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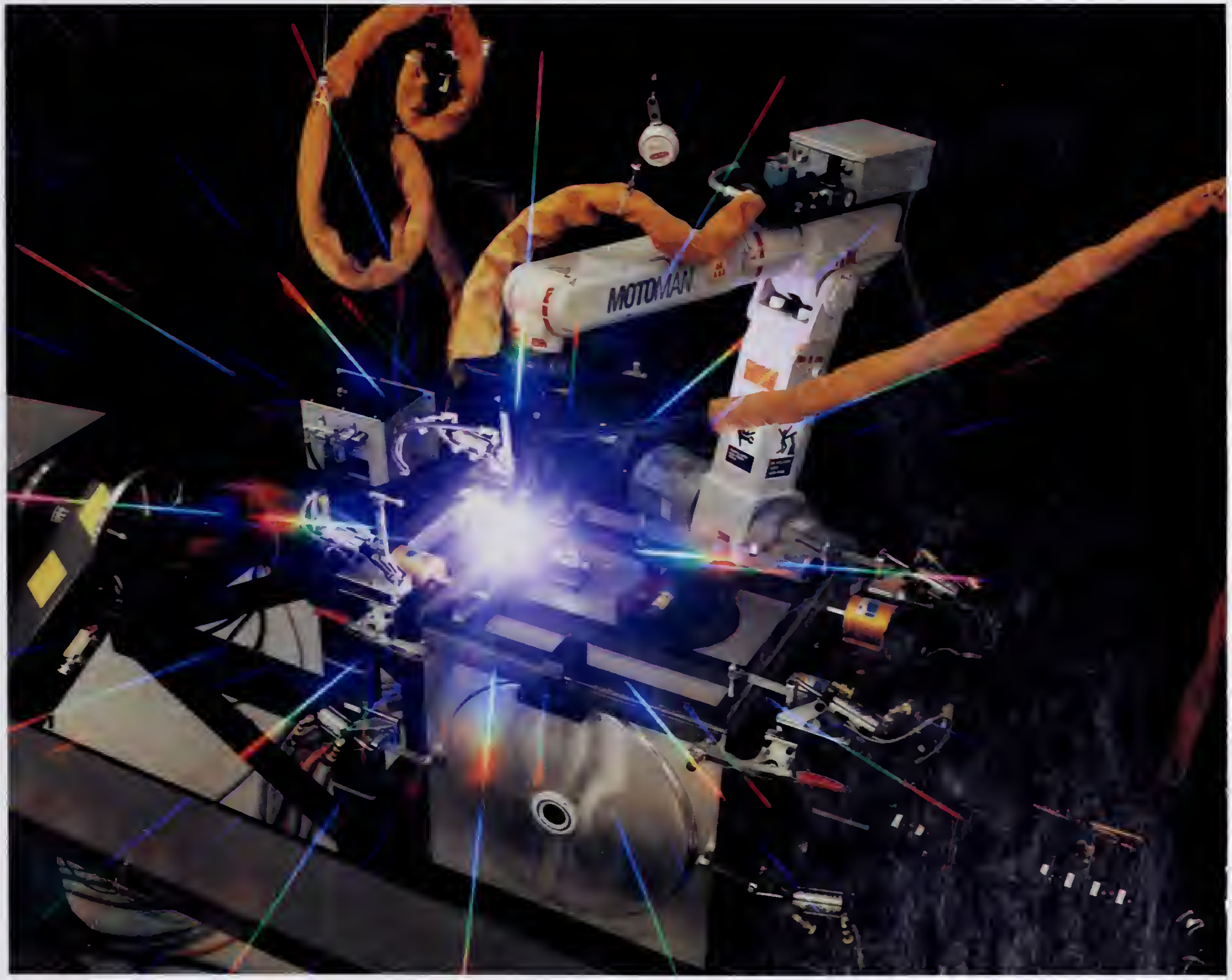
Laboratory Manual

Robotics Technology

James W. Masterson *Robert L. Towers* *Stephen W. Fardo*



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for

Robotics Technology

by

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INTRODUCTION

This **Laboratory Manual** and its accompanying **IBM AML Programming Software** is a supplement for the text, **Robotics Technology**. It is intended to help you carry out an in-depth study of robotic systems and the subsystems which comprise them.

Robotics is a very comprehensive, applications-oriented field of study. A complete understanding of this field involves many different technical areas such as electrical principles, electronic devices, digital principles, electromechanical fundamentals, basic programming techniques, hydraulics, pneumatics, and basic manufacturing processes.

The 52 laboratory activities in this manual will help you better understand many of these topics. The activities in Unit I—Principles of Robotics, make use of the IBM AML programming software included with this manual. The laboratory activities in Units II, III, and IV are hands-on activities.

The AML software, which has been adapted for educational use, was originally developed by IBM for use with its robots. The software will provide you with an opportunity to develop and compile simple robot programs, as well as simulate the actions of a robot on a personal computer. You will be working as if you were writing a program away from a robot's workstation (a common occurrence in industry). *A robot is not required; in fact, this version of AML would not be able to operate a robot if one was available.*

This manual, programming software, and **Robotics Technology** textbook, should provide a framework for your training as a robotics technician. You should supplement your knowledge by additional reading about the technical basics of robotics or by enrolling in additional courses as necessary. We are sure that you will find this Laboratory Manual a valuable tool in your learning experiences as a student of robotics.

James W. Masterson
Robert L. Towers
Stephen W. Fardo

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Principles of Robotics

Robot Programming with AML

The computer software provided with this manual is AML *(A Manufacturing Language)*, a programming language that was originally developed by IBM for use with its robots. The version that you will use was adapted for educational applications by Dr. Robert Towers, one of the co-authors of **Robotics Technology.**

You will use AML to write *programs*, or step-by-step instructions, for a robot. The program tells the robot everything it needs to know to accomplish a task: which direction to move, how far to move, and what to do at the end of the move (such as open or close a gripper). The programs that you develop as you complete exercises in this manual will be used to operate (in a computer *simulation*) the IBM 7535 Robot. See Figure 1. You will also write some programs for the IBM 7545 Robot, which is identical in shape and size to the 7535, but is more sophisticated. The 7545 is servo-controlled on all four major axes ("servos," or servomechanisms can detect errors and correct for them).

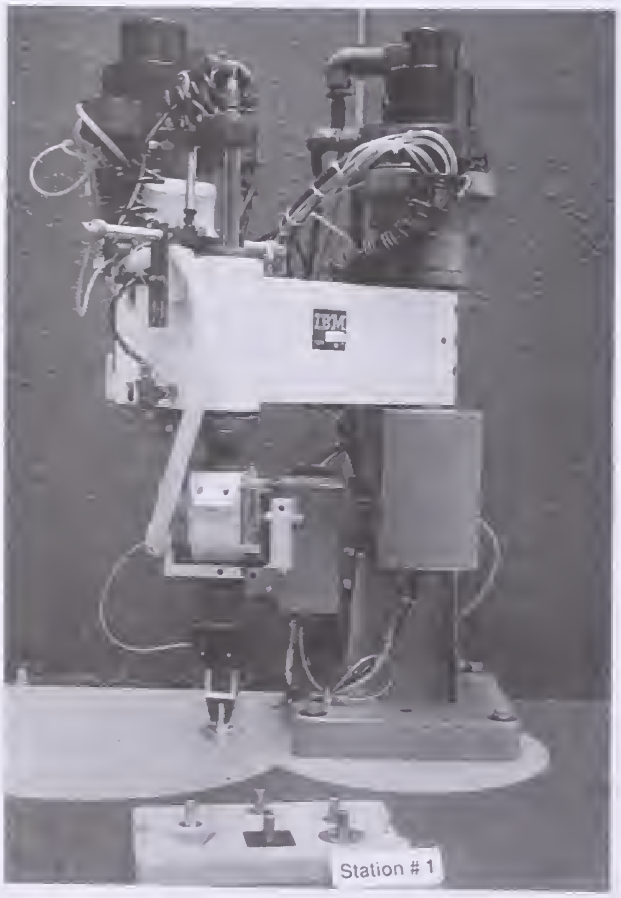


Figure 1 An IBM 7535 robot. The programs you write will be used to operate a simulated version of this robot or the somewhat more-sophisticated 7545 model.

As noted in the textbook, most robot manufacturers have developed *proprietary* languages for use with their robots. Even though these languages often are similar, each has its own set of keywords and commands. ***Keywords*** are words used in programs to identify parts of the program or actual objects, ***commands*** are instructions to ***execute*** (carry out) specific actions. Each program language also has its own syntax that must be properly used to communicate instructions to the robot. ***Syntax*** is the language's "structure," or the way that keywords, commands, and other information must be combined.

The following table shows the statements (keywords and commands) that are used for creating programs in the AML language. Additional information about each statement is available through the Help Menu in the software package.

AML Language Statements

Keywords

Name	**Description**
COUNTER	Identifies a counter.
END	Indicates the end of a program or subroutine.
NEW	Identifies a program constant.
PALLET	Identifies a pallet.
PT	Indicates coordinate values in the work envelope.
STATIC	Reserves controller storage for a counter or pallet.
SUBR	Declares or identifies a subroutine.

Commands

Name	**Description**
BRANCH	Command to go to a line containing a named label.
BREAKPOINT	Can interrupt and restart a program at any point.
DECR	Decreases a named counter by a value of 1.
DELAY	Delays the execution of the next program statement.
DOWN	Lowers the Z-axis (on IBM 7535 robot).
DPMOVE	Moves the manipulator a specific distance.

GETPART	Moves the robot manipulator on the named pallet.
GRASP	Closes the robot's gripper.
INCR	Increases a named counter by value of 1.
ITERATE	Repeats a command or subroutine using new values.
LINEAR	Controls straight line manipulator movement.
NEXTPART	Increases current part count by 1.
PAYLOAD	Controls the tool tip speed.
PREVPART	Decreases current part count by 1.
PMOVE	Moves robot manipulator horizontally.
RELEASE	Opens the robot's gripper.
SETC	Sets a named counter to a specified value.
TESTC	Tests a named counter for a specified value.
TESTI	Checks a digital input port for a true condition.
TESTP	Compares pallet's current part indicator to a value.
UP	Raises the Z-axis (on IBM 7535 robot).
WAITI	Instruction to wait for a specified digital input.
WRITEO	Opens or closes a digital output port relay.
ZMOVE	Controls Z-axis movement (on IBM 7545 robot).
ZONE	Controls tool tip tolerance.

Subroutines

The program instructions in AML are *subroutine-oriented.* A ***subroutine*** is actually a small program, with its own beginning and ending, that is used *within* the larger program. Subroutines are designed to accomplish some distinct action or purpose, such as picking up an object, moving to a specified point, or waiting for a certain period before carrying out an instruction. The main program can "call" (start) subroutines as needed to perform their tasks. Some subroutines may be used again and again in a program; others only once.

Each subroutine, as noted, has a beginning and an ending. The beginning of the subroutine is its name, commonly known as the ***identifier.*** The identifier is immediately followed by a colon (:), called the ***definition operator.*** Each subroutine terminates with an *end statement,* consisting of the keyword END and a semicolon (;). The semicolon, or ***statement delimiter,*** must be used to end every line in the subroutine, except comments. Figure 2 illustrates the functional parts of a subroutine.

The identifier must meet these criteria:

- Can be up to 72 characters.
- First character must be alphabetic (a letter).
- Remaining characters may be alphabetic, numeric (numerals), or underscores (_) in any combination. No special characters are permitted.

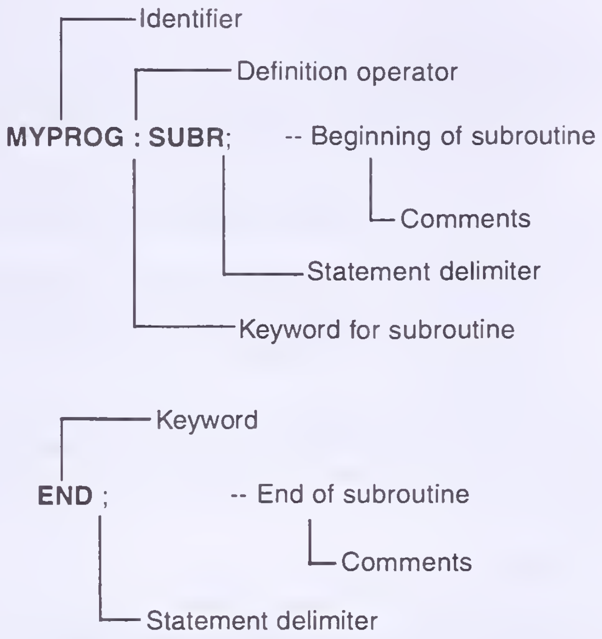


Figure 2 Functional parts of an AML subroutine.

Calling Subroutines

A program generally consists of two or more subroutines, each with a specific task. The main program calls each subroutine as needed. Subroutines can also call other subroutines. There are distinct rules for calling or executing subroutines:

1. A subroutine must be previously declared.
2. The called subroutines must be:
   a. on the same *level* as the calling subroutine, or
   b. owned by the calling subroutine.

Figure 3 illustrates these rules. The *main* subroutine can call both the pickup and putdown subroutines, since it satisfies rule 2b. The *putdown* subroutine can call the pickup subroutine, because it satisfies both rule 1 and rule 2a. The *pickup* subroutine cannot call the putdown subroutine, however, because it does not satisfy rule 1.

Structure of AML Programs

All AML programs have two major sections. One is referred to as the ***Global Declaration Section,*** the other as the ***Executable Section.*** The Global Declaration Section includes information (such as coordinates of locations) that may be applied by various subroutines in the program, while the Executable Section consists of commands to be carried out.

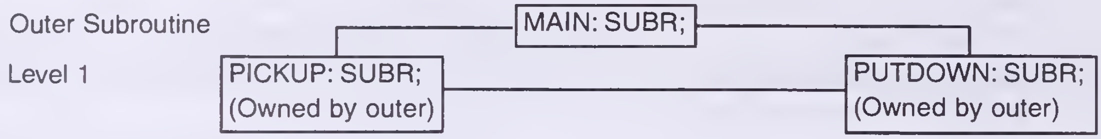

Outer Subroutine
Level 1
MAIN: SUBR;
PICKUP: SUBR; (Owned by outer)
PUTDOWN: SUBR; (Owned by outer)

Figure 3 Flowchart of the MAIN, PICKUP, and PUTDOWN subroutines.

These considerations must be kept in mind when developing AML programs:

- The program name can be up to 8 characters long. It can include letters, numbers, and underscores, but must start with a letter.
- A colon (:) must be used between an identifier (such as "MAIN") and a keyword ("SUBR", for example).
- Each line of a program (except a comment) must end with a semicolon (;). Comments can be included by beginning their text with two hyphens (--).

Following is a short sample program that illustrates the preceding considerations. It is used to move the robot's end effector (hand) to location A, then to location B.

```
EXE_2.AML
------------------Global Declaration Section------------------
A:NEW PT(X,Y,R); --XYR location to be taught
B:NEW PT(X,Y,R); --XYR location to be taught

----------------------Program Execution---------------------
MAIN:SUBR;
PMOVE(A); --move to point A
PMOVE(B); --move to point B
END;
```

More detailed information about various aspects of AML programming will be provided as you progress through the activities in this unit of the *Robotics Technology Laboratory Manual.* More information regarding the terms used in this example can be found in the Help Menu in the software package.

Installing the IBM AML Programming Language Simulator

System Requirements:

IBM-compatible computer with at least a 286-generation microprocessor, 2MB RAM, 3.5 inch floppy disk and a hard drive with 1.5 MB free space, mouse, VGA color display.

Hard drive installation:

1. Turn on the computer and monitor.
2. When the **C:\>** prompt appears on the screen, type **MKDIR ROBOT** and press ENTER.
3. Type CD\ROBOT and press ENTER to switch to the directory you have just created.
4. Your command prompt should look like this:

   C:\ROBOT>

5. Put the disk containing the AML Programming Simulator into the 3.5 inch floppy disk drive. Type

   COPY A:*.*C:

   and press ENTER.

   A is the letter typically assigned to the 3.5 inch drive containing the AML Programming Software (this drive could use B or another letter). C is the letter typically assigned to your hard drive.
6. This will copy the AML simulator to your hard disk. To start the simulator, type in AML and press ENTER.

Floppy drive operation:

You can run the AML Simulator from the original disk. The only requirement is that your computer must have two floppy disk drives, one for the program and one for the data disk. You cannot run the AML Simulator from a single floppy disk drive.

Activity 1—Programming Environment

Name ____ Date ____________________ Score ____________

Objectives:

The purpose of this exercise is to provide hands-on activities in working with the AML Programming Language that has been revised for use with the **Robotics Technology** textbook. The knowledge you gain from using this programming language will help you have a better understanding of other robot programming languages.

After completing this exercise, you will be able to:

- Δ Boot up the computer, call up the AML Programming Environment, and move among the program menus.
- Δ Create a robot program, teach point location positions, successfully compile the robot program, and run it on the program simulator.

Equipment and Materials:

- IBM-compatible computer with mouse and VGA color display.
- Robotics Technology Programming Software package.
- Printer to produce a hard copy of your program.

Procedure:

Note: The procedure that follows assumes that the AML Robotics Technology Programming Software has been installed on the computer's hard disk drive (designated as "C:" on most systems). If your software has not yet been installed on the hard drive, or if you are using a system with two floppy drives, refer to Installing the IBM AML programming Language Simulator on Page 8.

1. Turn on the computer and monitor. Insert a blank, formatted disk in the floppy drive.
2. When the C:\> prompt appears on the screen, type CD\ROBOT. Press the ENTER key.
3. Type AML and press ENTER. The Programming Menu will appear on screen, Figure 1-1.

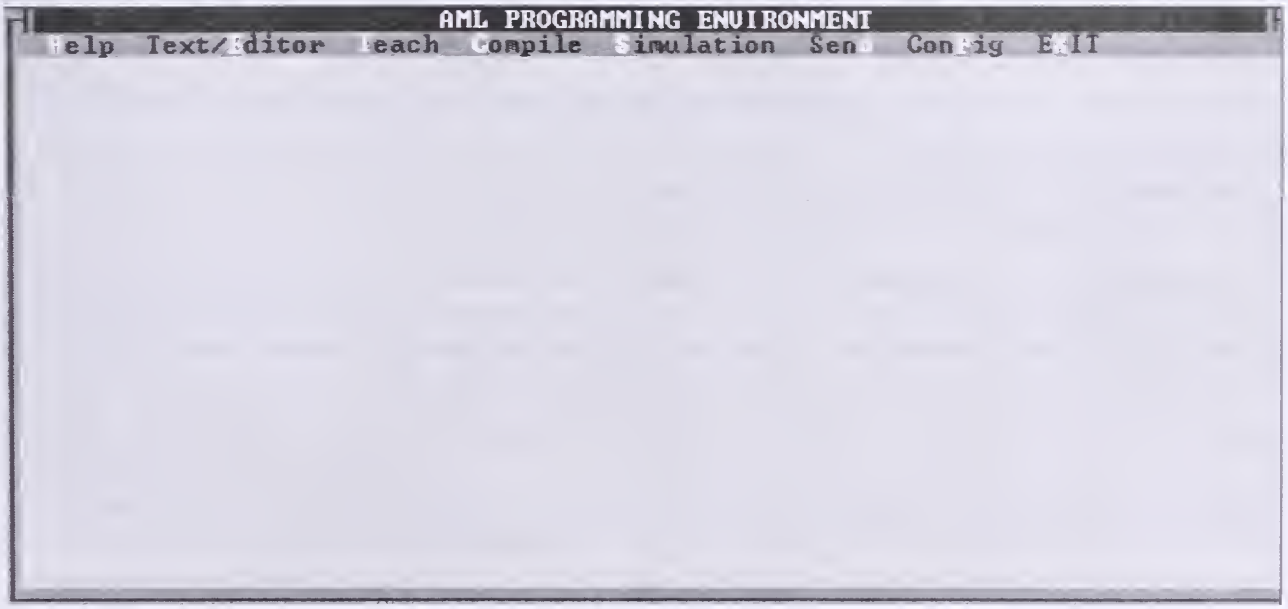


Figure 1-1 Programming Menu Screen.

4. Move the mouse until the cursor (usually, a small blinking square) is on the word Help. Press ("click") the left mouse button to bring up the Help Menu.
5. Select (place the cursor on, then click) the word Logo. The Software Information Menu will then appear. Click on OK to return to the Main Menu.
6. Click on Help again. This time, select System Help. You can use this to find out more information about the menu commands. Select one of the headings listed on the left of screen (for example: Teach) and read the text accompanying it. Click on Exit Help to return to Main Menu.
7. Click on Help again. Select AML/Programming. Information on AML programming commands and keywords can be retrieved by using this menu. Examine several entries, then click on Exit Help to return to Main Menu.

   Now that you are familiar with the help screens you can move on to learning about programming. First, you will type in a short program, then save it. You will also gain experience in using the Teach mode, compiling your program, and running it as a simulation.

8. Select Config from the Main Menu. Set the robot configuration to 7535.
9. Return to Main Menu, and select Text/Editor. Carefully type the following. Use only *CAPITAL* letters and be sure to use the *exact* spacing and punctuation shown.

```
MAIN:SUBR;
 PMOVE(PT(100,200,0));
 DOWN;
 GRASP;
 DELAY(.5);
 UP;
 PMOVE(PT(100.0, 200.0, 0.0));
 DOWN;
 RELEASE;
 DELAY(.5);
 UP;
END:
```

10. Click on File. You will now save the program file to your data disk, which is located in the floppy disk drive, "A" is most common. If your drive is "B," type that letter, instead. To save the file, select Save As, then type in the file name A:EXER1.AML. Press the ENTER. To leave the Text/Editor, select File again and click on Exit.
11. At the Main Menu, select Teach. When prompted for the file name, type in A:EXER1.AML

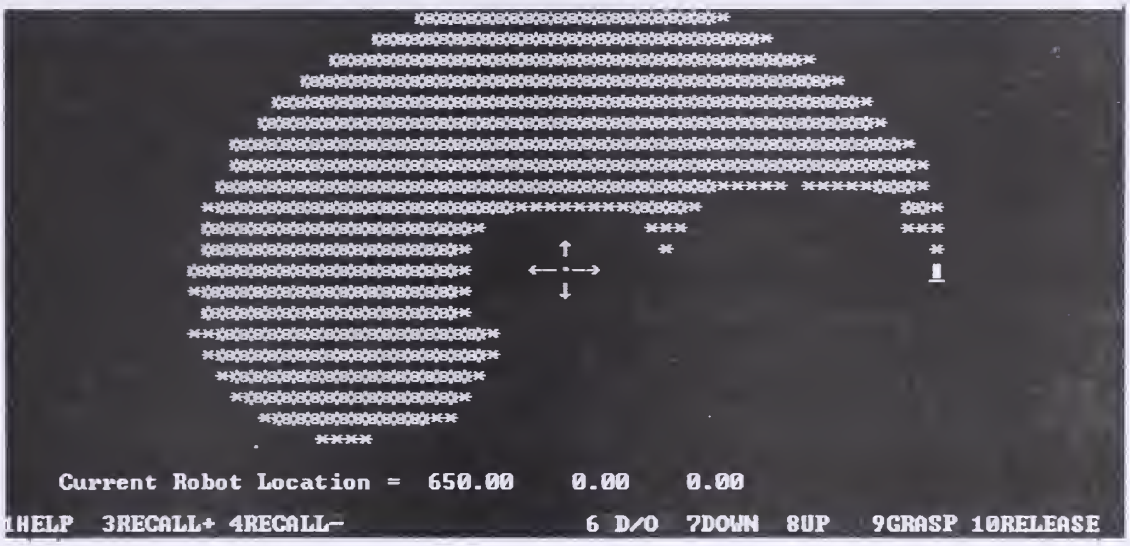
    The Teach mode allows you to edit the point positions in the work envelope. This can be done automatically by the program, or manually by using the keyboard. You will change the points in the program you have just coded; first by entering the points into the program, then by using the keyboard.

12. Press the F6 key. The following message should appear on screen:

```
COMMUNICATIONS ERROR
Check that controller is ON-LINE and cable is attached
Abort teach? (y [yes], n[no], i[ignore])__
```

    If your computer was connected to a robot controller, you could download the program directly to the controller. You will be programming as if you were writing a program away from the robot's work cell. Type the letter I and ENTER. A representation of the robot work envelope will appear on the screen, Figure 1-2.

Name ____



```
Current Robot Location =  650.00     0.00     0.00
```

Figure 1-2 Robot Teach Screen.

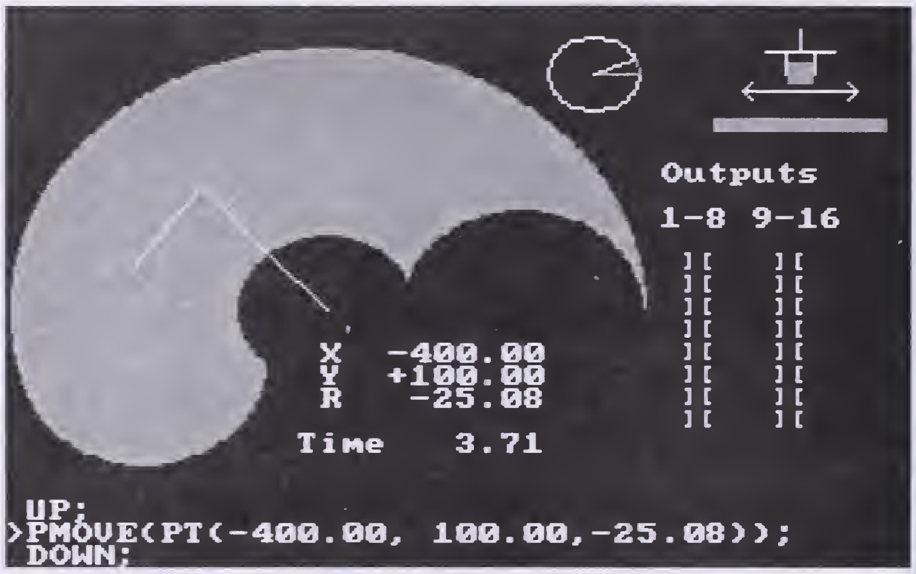
13. Here, you will enter in the new work envelope values and let the program adjust the robot's manipulator. Press the ESC key. Type the number 300 and press ENTER. Type the number 400 and ENTER. Type the number –150 (Note the minus sign), then press ENTER. After you have entered the new values, you will see the cursor move to the robot location of X = 300, Y = 400, R = –150.
14. Press the END key. Move cursor to the second parenthesis in line 2. Press the F7 key to recall the robot point location. (You will need to insert a right parenthesis) before the semicolon in line 2 because one of them will be copied over by the teach program.)

    Now you will learn how to adjust manipulator position manually by using the keyboard.
15. Move the cursor to the second parenthesis in line 7. (PMOVE(PT(100.0, 200.0, 0.0));
16. Press the F6 key. While holding down the Shift key, use the Arrow keys on the numeric key pad to move the robot to X = –400, and Y = –100. For finer control movements, do not press the Shift key. Use the PgUp or PgDn to where R = 25.00 (approx.).
17. Press the End key and press the F7 key to recall the robot point location. Be sure to insert a right parenthesis) before the semicolon in line 7.

    ```
    (PMOVE(PT(–400.0, –100.0, 25.00);
    ```
18. Press F8 key to save your program changes. Return to the Main Menu.

    Next, you will compile the program. The purpose of the compiler is two-fold. First, it checks for errors in your programing; second it converts the English-like AML statements to computer machine code.
19. Select Compile and type the filename EXER1. Type N after the hard copy, .lst, and .sym prompts.

    An error message will appear on the screen concerning the END statement. Ignore this message – press any key to return to the Main Menu.
20. Select Text/Editor. Type in the filename EXER1. Move the cursor to the END statement and change the colon (:) to a semicolon (;). Save the file and exit to Main Menu.
21. Repeat the steps listed in item (20). The message, Successful Compilation, will appear on the screen. Press any key to return to the Main Menu.
22. Select Simulation. You will get a prompt asking you if you want to change the model number of the robot you wish to simulate. Press ENTER at this prompt.
23. Type in EXER1 for file name. Type the letter N after the change input and metric to inches prompt. On the screen, you will see a simulation of a robot carrying out the program you have written, Figure 1-3.



```
X    -400.00
Y    +100.00
R     -25.08

Time    3.71

 UP;
>PMOVE(PT(-400.00, 100.00,-25.08));
 DOWN;
```

Figure 1-3 Robot Simulation Screen.

24. At the End of Program. Repeat [y:n]_ prompt, ENTER Y to run program again. You can print a hard copy of program run times by typing Y at the print timing report prompt. If you do not have a printer connected, type N. You will exit the simulator program.
25. Go back to the Text/Editor and open EXER1. Click on the File menu and select Print. This command will print a hard copy of your program. Click again on File and on Exit to return to the Main Menu.
26. At the Main Menu, select Exit to leave the program. Remove your data disk and turn off the computer.

Analysis:

1. What programming statement (command) causes the robot to move to a point location?
2. List the steps needed to run a successfully compiled program on the simulator.
3. What are two purposes of the compiler?

Name ______________________________

4. While in the teach mode, what two methods can be used to move the robot to a particular point location?

5. What menu would you choose to find information about a programming command?

6. Which function key is used to make the work envelope appear on the screen in the teach mode?

7. What steps are used to recall the data into the text portion of the program after teaching a point location?

8. How do you bypass the communication error message and make the work envelope appear on the screen?

9. How many seconds does the program take to execute (run) on the simulator?

Activity 2—Movement of Peg Activity

Name ____ Date __________________ Score ___________

Objectives:

One of the most common tasks performed by robots in industry involves pick and place activities. The purpose of this exercise is to write a program to move three pegs from one peg holder to another, while at the same time controlling the movement speed of the robot.

After completing this exercise, you will be able to:

- Δ Write a program that will move three pegs from one holder to another while varying the speed of the robot's movements.
- Δ Teach point location positions, compile the robot program, and run program on the program simulator.

Equipment and Materials:

- IBM-compatible computer with mouse and VGA color display.
- Robotics Technology Programming Software package.
- Printer to produce a hard copy of your program.

Note: The illustrations in this activity are meant to give you an idea of the physical relationship between a robot and the supporting material referred to in the activity. The purpose of these exercises is to teach the basics of robot programming. This programming exercise will be done entirely on the computer without any additional laboratory equipment.

Procedure:

1. Turn on the computer and monitor. Insert your program disk in the floppy drive. At the C:\> prompt type CD\ROBOT and press ENTER. Type AML and press ENTER to start the programming menu.
2. Refer to Figures 2-1 and 2-2 for equipment layout in this exercise.

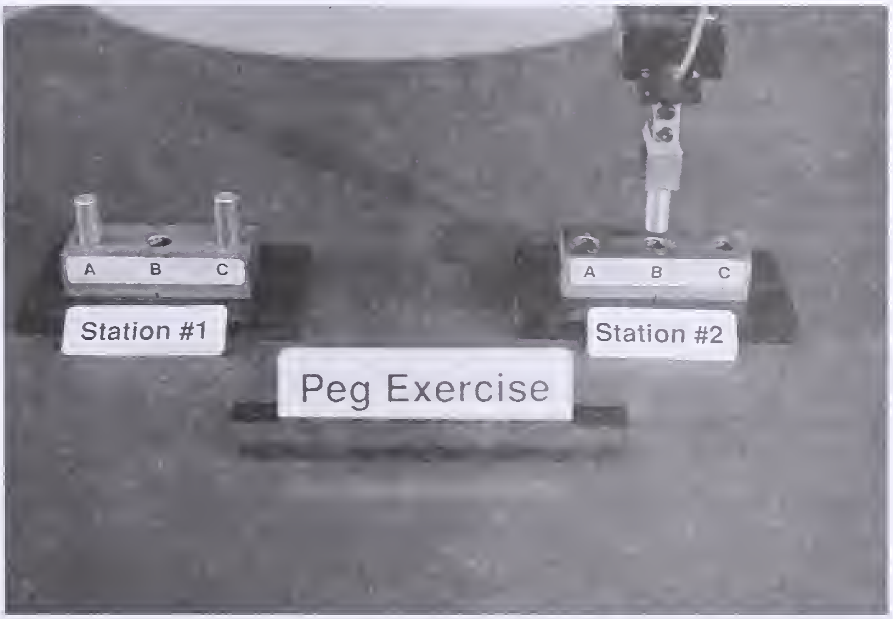


Figure 2-1 Equipment layout for Activity 2.

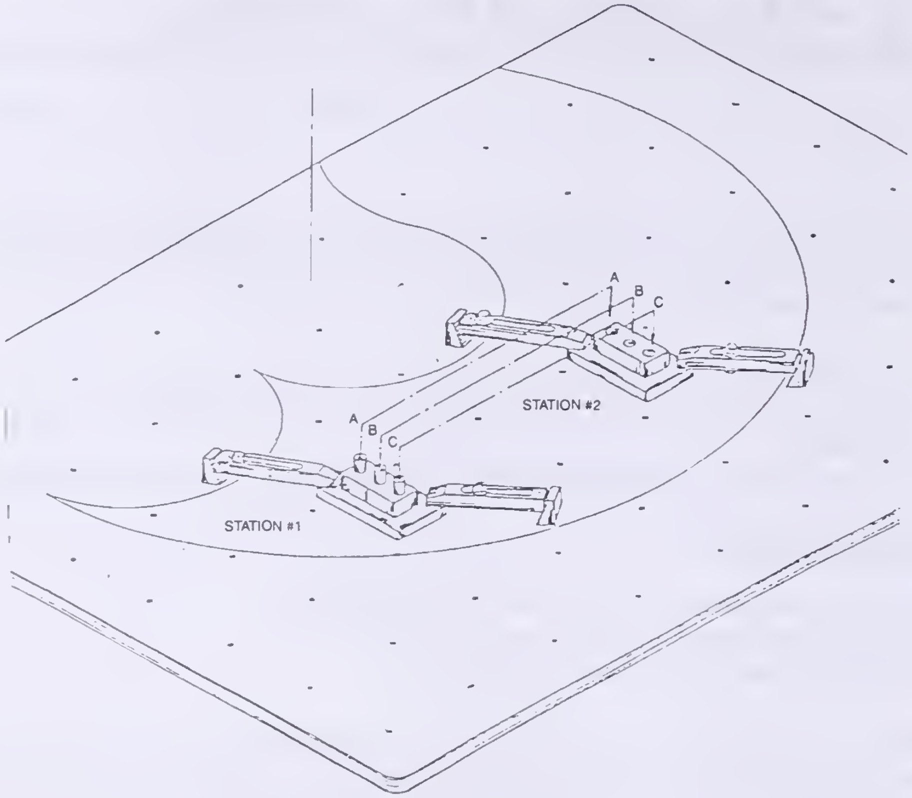


Figure 2-2 Plan view layout of equipment for Activity 2.

3. You will be using a four axis IBM 7535 Robot (see Figure 1 in Principles of Robotics).

The Z axis on the IBM 7535 is a non-servo control axis. Because of this, the robot is only capable of stopping at two positions along the Z axis, either fully up or down. The robot is equipped with an air-actuated gripper. A delay statement will have to be used in your program whenever the gripper is opened or closed. Use the following programming statements and keywords to construct your program. Refer to the Help Menu in the programming software for additional assistance.

AML Commands and Keywords

DELAY(sec.) --delays the execution of next statement (.1- 25.5)
DOWN --lowers the Z-axis
END --keyword required for each subroutine
GRASP --closes gripper
NEW --keyword to identify a constant (a constant may be a number, point, or character string)
PAYLOAD(value) --controls the tool-tip speed (1-10) 1 for slowest, 10 for fastest
PMOVE(point) --moves manipulator horizontally from one location to another
PT --keyword that indicates three value (X,Y,R) name:NEW PT(X,Y,R); or PMOVE(PT(X,Y,R));
RELEASE --opens gripper
SUBR --keyword that declares or identifies a subroutine.
EXAMPLE: id:SUBR; or id:SUBR(parameter);
UP --raises the Z-axis

4. Before constructing your program, click on Config from the Main Menu and select 1 to set the robot configuration. Set the configuration for the 7535 robot and press ENTER. Save your settings by pressing 4 and ENTER.

5. Click on the Text/Editor and begin writing your program using only CAPITAL letters.. On the first few lines, use comment statements to explain the function of the program. Comment statements on each line of the program must be proceeded by a double hyphen (--).

Name ____

6. In the Global Declaration Section of the program define the six point locations that are to be used in the program. An example of how to structure your initial point locations is shown below:

```
(Example: Location " A" on Station #1).
A1:NEW PT(0.0,0.0,0.0);
```

Do not be concerned with actual point locations in the work envelope at this time. Your instructor will give you the actual point locations. You will use the Teach program to teach the robot the actual point locations.

The ***Global Declaration Section*** in an AML program includes information, such as coordinates, that may be applied by subroutines in your programs. See program example EXE_2.AML below.

```
EXE_2.AML
---------------Global Declaration Section---------------
A:NEW PT(X,Y,R); --XYR location to be taught
B:NEW PT(X,Y,R); --XYR location to be taught
--------------------Program Execution--------------------
MAIN:SUBR;
PMOVE(A); --move to point A
PMOVE(B); --move to point B
END;
```

7. Identify or name the main subroutine. See the Help section of the software concerning an identifier for a subroutine or consult the Introductory Unit.

8. After you have named the main subroutine, write a user subroutine that will pick up parts. User subroutines are written by you as you develop the program. It is to your advantage to write a subroutine and keep calling it wherever some action is repeated in other parts of the program. Consult the Introductory Unit or the software Help Menu concerning the calling of subroutines.

(Example)

```
MYPROG:SUBR;
   PICKUP:SUBR;
      UP;
      RELEASE;
      DELAY(.5);
      DOWN;
      GRASP;
      DELAY(.5);
      UP;
END;
```

9. Write another user subroutine to put the part down.

10. You are now ready to write the execute portion of the program. The execute section of the program contains all of the commands to be carried out. Write a program that will pick up the three pegs located on station #1 and move them to station #2. When the gripper is empty move the robot at its fastest speed. When the gripper is carrying a part move the robot at its slowest speed.

Always start this portion of the program with an UP command for robots that do not have a servo-controlled Z axis and a ZMOVE of 0 for those robots with servo-controlled Z axis. End the execute portion of the program with an END statement. To help you get started, the execute portion of the program would begin as follows:

```
---------------- Program Execute----------------(This is a comment)
UP;
PAYLOAD(10);      --move at fastest speed
PMOVE (A1);       --move to location A at Station #1
PICKUP;           --pick up peg
PAYLOAD(1);       --move at slowest speed
PMOVE (A2);       --move to location A at Station #2
PUTDOWN;          --put down peg
```

11. Save as file as EXER2.AML.

12. Select Teach and type in EXER2 for the file name.
13. Press the F6 key. When the communication error message appears on screen, type the letter I and ENTER to get to the robot work envelope.
14. While holding down the Shift key, use the Arrow keys on the Numeric keypad to manually move the robot to the approximate (X,Y) location for point A1. For finer control movements, do not press the SHIFT key. Use the PGUP and PGDN keys to change the wrist movement (R). Your instructor will give you the locations for all six points to be taught.
15. After you have taught the first point location, press the END key. Place the cursor on the left parenthesis (for the point you were teaching. Press the F7 key to recall the robot point location into the text of the program. Add a right parenthesis before the semicolon.
16. To teach the remaining point locations, repeat steps 12-14. After teaching all points, press the F8 key to save program changes and return to the Main Menu.
17. Select Compile, type in EXER2 and compile the program. If any error messages are given, see your instructor.
18. If the program compiles successfully, return to the Main Menu.
19. Select Simulation. Do not change the model of the robot (7535).
20. Enter EXER2 for file name and ENTER. Type N at the two prompts and run the simulation. Enter Y to run the program again. Print a hard copy of program run times by typing Y at the print timing report prompt. If not, type N and press ENTER to exit the simulator program.
21. Go back to the Text/Editor and open EXER2. Click on the File menu and select Print. This command will print a hard copy of your program. Click again on File and on Exit to return to the Main Menu.
22. Select Exit to exit the Main Menu. Remove your data disk and turn off the computer.

Analysis:

1. What characters are used before each comment?

   --

2. What would happen if you failed to place a semicolon on one of the lines in the program?

   The program will fail during compilation

3. Why is it important to begin the executional portion of the program with an UP statement?

   For safety [illegible] good [illegible] practice [illegible] robot [illegible]

   [illegible]

   [illegible] raise [illegible] along path [illegible] 2 [illegible]

   [illegible]

4. Write a declaration statement for a point location at "F" with an X=150, Y=350, R=-125.0.

   F NEW PT(150, 350, -125.0)

5. The main subroutine in the program is able to call both the pickup and putdown subroutines. The putdown subroutine can call the pickup subroutine; however, the pickup subroutine cannot call the putdown subroutine.

Name ______________________________

How is this possible?

6. When would you write a user subroutine? What advantage do you gain by using subroutines?

[illegible]

When an action is repeated in a program. Subroutines save time by

eliminating having to write syntax for an action that is done

over and over during a program. Also

Activity 3—Writing Subroutines with Formal Parameters

Name ____ Date ____________________ Score ____________

Objectives:

The program you wrote in Activity 2 was quite long and several commands were repeated in the execute portion of the program. The purpose of this exercise is to revise the program using formal parameters in the user subroutines. A formal parameter is any number or string of values that can be entered into a subroutine. The program will then call and pass the defined parameters through those subroutines.

After completing this exercise, you will be able to:

- Δ Simplify programs by writing user subroutines employing formal parameters.
- Δ Call user subroutines with parameters and pass those values in the body of the program.

Equipment and Materials:

- IBM compatible computer with mouse and VGA color display.
- Robotics Technology Programming Software package.
- Printer to produce a hard copy of your program.

Procedure:

1. Turn on the computer and monitor. Insert your program disk in the floppy drive and at the C:\> prompt, type CD\ROBOT and press ENTER. Type AML and press ENTER to start the programming menu.
2. In this exercise you will revise the program that you wrote for Activity 2. You will rewrite the two user subroutines inserting formal parameters to pick up and put down the pegs. The following example demonstrates the use of formal parameters and how they are passed in the program.

```
A:NEW PT(100.0, –150.0, 120.0); -- global declaration
  MYPROM:SUB;
    PICKUP:SUBR(PLACE, TIME);
       PMOVE(PLACE);
       DOWN;
       GRASP;
       DELAY(TIME);
       UP;
    END;
-------------------Program Execution-------------------
    UP;
    PICKUP(A, 1.0);  -- robot move to (A) location as defined in
                     -- the Global Declaration Statement and the
                     -- time for the (DELAY) statement is set to
                     -- one second.
END;
```

3. Place the payload statements in the user subroutines so you do not have to repeat them in the execute portion of the program. Change the payload statement to 7 for fast movements and to 3 for slow movements.

   In addition to rewriting the subroutine, expand the execute portion of the program to move the pegs back to station #1. After the pegs have been returned to station #1 move the robot manipulator arm to its home position. The home position is defined as follows:

   ```
   HOME:NEW PT(650.0, 0.0, 0.0);
   ```

4. Select Text/Editor and open EXER2.AML. This is the program you created for Activity 2.
5. Rewrite the program to reflect the changes as outlined in steps 2 and 3. Save your program as EXER3.AML.
6. Select Compile and type in EXER3. Compile the program to check for errors. If you encounter any problems, see your instructor.
7. If the program compiles successfully, return to the Main Menu.
8. Select Simulation. Do not change the model of the robot (7535).
9. Enter EXER3 for file name. Type the letter N at the three prompts and press ENTER. A simulation of the program will run on the screen. Enter Y to run program again. You can print a hard copy of program run times by typing Y at the print timing report prompt. If not enter N to exit simulator program.
10. Go back to the Text/Editor and open EXER3. Click on the File menu and select Print. This command will print a hard copy of your program. Click again on File and on Exit to return to the Main Menu.
11. Select Exit to leave the Main Menu. Remove your data disk, then turn off the computer and monitor.

Analysis:

1. What is the advantage of writing user subroutines with formal parameters?

   ____

2. Write a user pickup subroutine employing parameters and one that does not use parameters.

Name ____

3. Which Payload statement has the fastest movement?

   PAYLOAD(2) ______

   PAYLOAD(5) ______

   PAYLOAD(10) ______

4. You are given the task of writing a Payload statement at only two places in the program. Where would you place the statements so you can vary the speed of the robot when the gripper is either empty or carrying a part?

   ____

5. How would you write that portion of the program to accomplish the task of varying the speed of the robot?

Activity 4—Creating Cycles

Name ____Date ____________________Score ____________

Objectives:

In programming, there are occasions when it is necessary to run the same program a certain number of times. This is accomplished in the AML Language by using a ***counter.*** In manufacturing, a counter makes it possible to produce a specified number of parts by counting non-rejected assemblies.

In this exercise you will only be concerned with running the program a specified number of times. You will write a program to move parts from one location to another and back again for a prescribed number of times. You will declare the counter by using the keyword STATIC. There are four other statements that are used with the counter. They are:

SETC(name,value) -- Sets a named counter to a specific value
INCR(name)-- Increases a named counter by a value of 1
DECR(name) -- Decreases a named counter by a value of 1
TESTC(name,value,label). -- Tests the named counter for a specific value

After completing this exercise, you will be able to:

- Δ Develop a program incorporating BRANCH statements and COUNTER statements.
- Δ Run a program a prescribed number of times.
- Δ Revise the COUNTER statements in order to change the number of cycles.

Equipment and Materials:

- IBM-compatible computer with mouse and VGA color display.
- Robotics Technology Programming Software package.
- Printer to produce a hard copy of your program.

Note: The illustrations in this activity are meant to give you an idea of the physical relationship between a robot and the supporting material referred to in the activity. The purpose of these exercises is to teach the basics of robot programming. This programming exercise will be done entirely on the computer without any additional laboratory equipment.

Procedure:

1. Turn on the computer and start the AML programming software.
2. Refer to Figures 4-1 and 4-2 for equipment layout for this exercise.
3. For this exercise you will be using a four axis IBM 7535 Robot.

A DELAY statement must be used in the program when the gripper is closed or opened. You are to use the following commands and keywords in addition to the ones you have already learned. Refer to the Help Menu in the programming software for additional assistance in writing your program.

Additional AML Commands and Keywords

STATIC -- this keyword reserves controller storage for a counter or pallet. The structure of a STATIC COUNTER would look like:

```
name:STATIC COUNTER
```

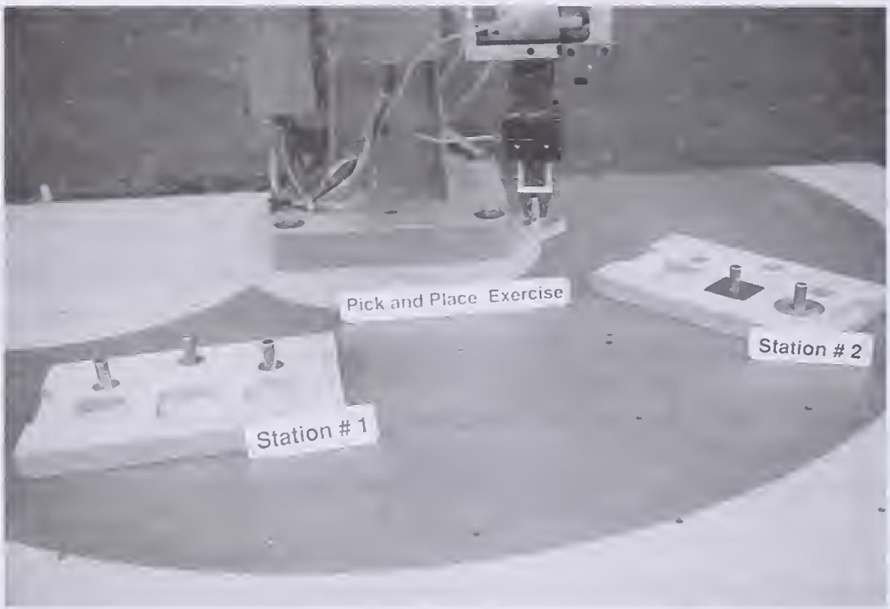


Figure 4-1 Equipment layout for Activity 4.

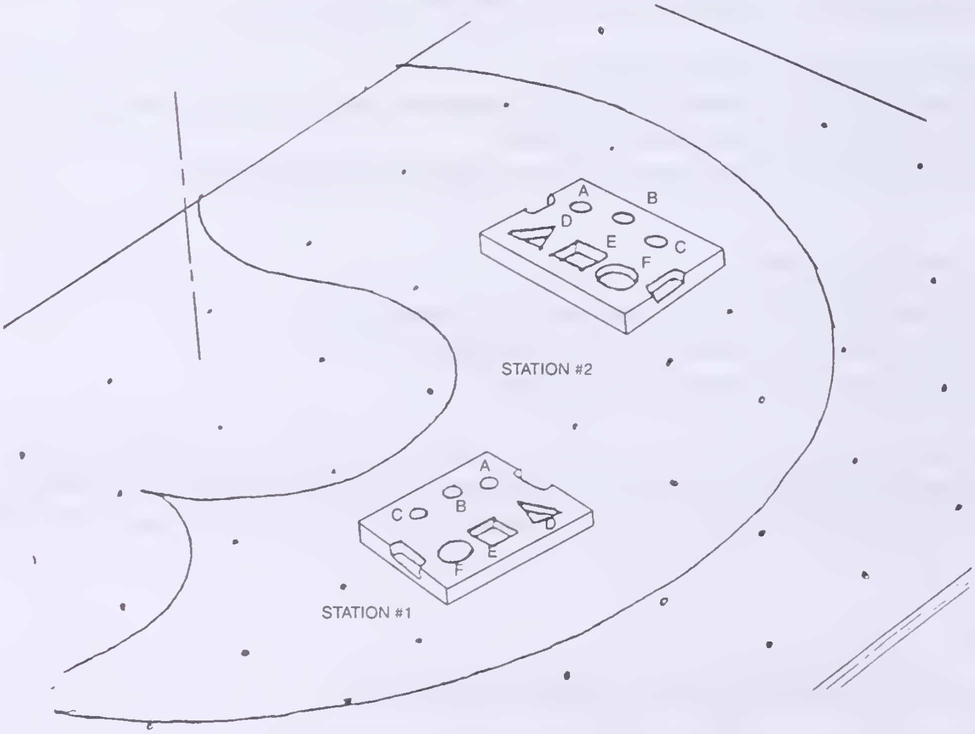


Figure 4-2 Plan view layout of equipment for Activity 4.

Your STATIC statements will look like the ones shown below. The examples names are ALPHA and BETA.

```
ALPHA:STATIC COUNTER;
BETA:STATIC PALLET;
```

BRANCH (label) -- allows you to branch to a line in the program containing a named label. The label must appear in the same subroutine as the BRANCH statement, however.

SETC (name, value) -- sets the named counter to a specified value.
DECR (name) -- decreases the named counter by a value of 1.
INCR (name) -- increases the named counter by a value of 1.
TESTC (name, value, label) -- tests the counter for a specified value.

Name ____

Program example

```
A:NEW PT(100.0, -150.0, 120.0);    -- global declaration point location
B:NEW PT(-200.0, 175.0, 100.0);    -- global declaration point location
HOME:NEW PT(650.0, 0.0, 0.0);      -- global declaration home location
CYCLE:STATIC COUNTER;              -- counter identified
  MYPROM:SUBR;

---------------------Program Execution---------------------
 SETC (CYCLE, 1); -- sets counter to a value of 1
 REPEAT: -- label in branch statement, line #15
 UP;
 PMOVE(A);
 PMOVE(B);
 DELAY(3.0);
 TESTC(CYCLE, 4, STOP); -- checks counter for a value of 4; if it
                        -- is not the fourth time through, then
                        -- program executes the next line. If the
                        -- condition is met it moves to the label
                        -- STOP.
INCR(CYCLE);            -- increases the value of the counter by 1
 BRANCH(REPEAT);        -- branches to line # 8
 STOP;
 PMOVE(HOME); --moves to home position
END;
```

4. At the beginning of the program use comment statements to explain the purpose of the program. Remember comment statements on each line of the program must be proceeded by the double hyphen (--).

5. In the Global Declaration Section of the program define the twelve point locations that are to be used in the program and the STATIC COUNTER. An example of how to structure your initial point locations is shown below:

   (Example: Location "A" on Station #1).

   `A1:NEW PT(0.0,0.0,0.0);`

Do not be concerned with actual point locations in the work envelope at this time. Your instructor will give you the actual point locations. You will use the Teach program to teach the robot the actual point locations.

6. Finish writing the program where all parts on Station #1 are moved to Station #2 and then moved back to Station #1. Write the program so that it will repeat this process four times. Save program as EXER4.AML.
7. Compile the program. If you have any problems, see your instructor.
8. After the program is successfully compiled, run it twice on the Simulator. Print a timing report and a copy of the program.
9. Exit the AML program and turn off the computer.

Analysis:

1. What syntax identifies the STATIC COUNTER in the Global Declaration Section of the program?

____

____

2. Why are BRANCH statements generally placed in the execute portion of the program?

3. What statement checks the counter?

4. What will happen in the program if the value in the counter is not met? What happens when the value *is* met?

5. Write a user subroutine containing a BRANCH statement. Explain what occurs in the user subroutine.

Activity 5—LINEAR, Speed, and ZONE Commands

Name ______________________________ Date ______________ Score __________

Objectives:

The default manipulator movement for the IBM 7535 and 7545 Robots is an arc-type movement between points. The ZONE and PAYLOAD values default to switch settings inside the controller of the robot. However, there are times when point location is more critical or the robot movement needs to follow more of a straight line between points. To accomplish this, the following AML commands are used.

PAYLOAD (value) -- the value range is 1-10. A value of 1 produces the slowest possible movement. A value of 10 is the fastest movement. A value of 0 causes the robot to default back to the switch settings in the controller.

LINEAR (value) -- the value range is 1-50. A LINEAR statement with a value of 1-50 will override a PAYLOAD statement. A value of 1 produces the straightest movement and the slowest speed. This value causes the program to place intermediate points between defined point locations 1 millimeter apart. A value of 50 places the points every 50 millimeters. A value of 0 causes the robot to default back to an arc movement. LINEAR statements can be executed only within the linear area of the work envelope. See Figure 5-1 for an example of the effect of LINEAR statement values on end effector movement.

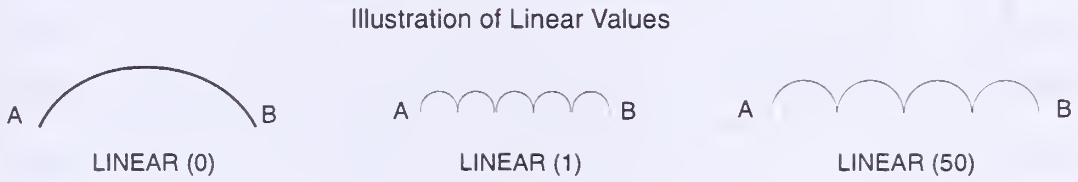


Figure 5-1 Illustration of LINEAR Statement values.

ZONE (value) -- the value range is 1-15. A value of 1 produces the closest tolerance and requires more settling time. Settling time is the amount of time needed for the tool tip to reach the programmed point. This makes the ZONE statement useful in applications where tool tip placement is crucial. A value of 15 is more forgiving and requires less settling time. A value of 0 causes the robot to default to the switch settings in the controller.

You will write a program that will move the robot's manipulator to seven separate points in the work envelope. The manipulator will start from its home position.

After completing this exercise, you be able to:

- Δ Develop programs that incorporate the use of PAYLOAD, LINEAR, and ZONE statements.

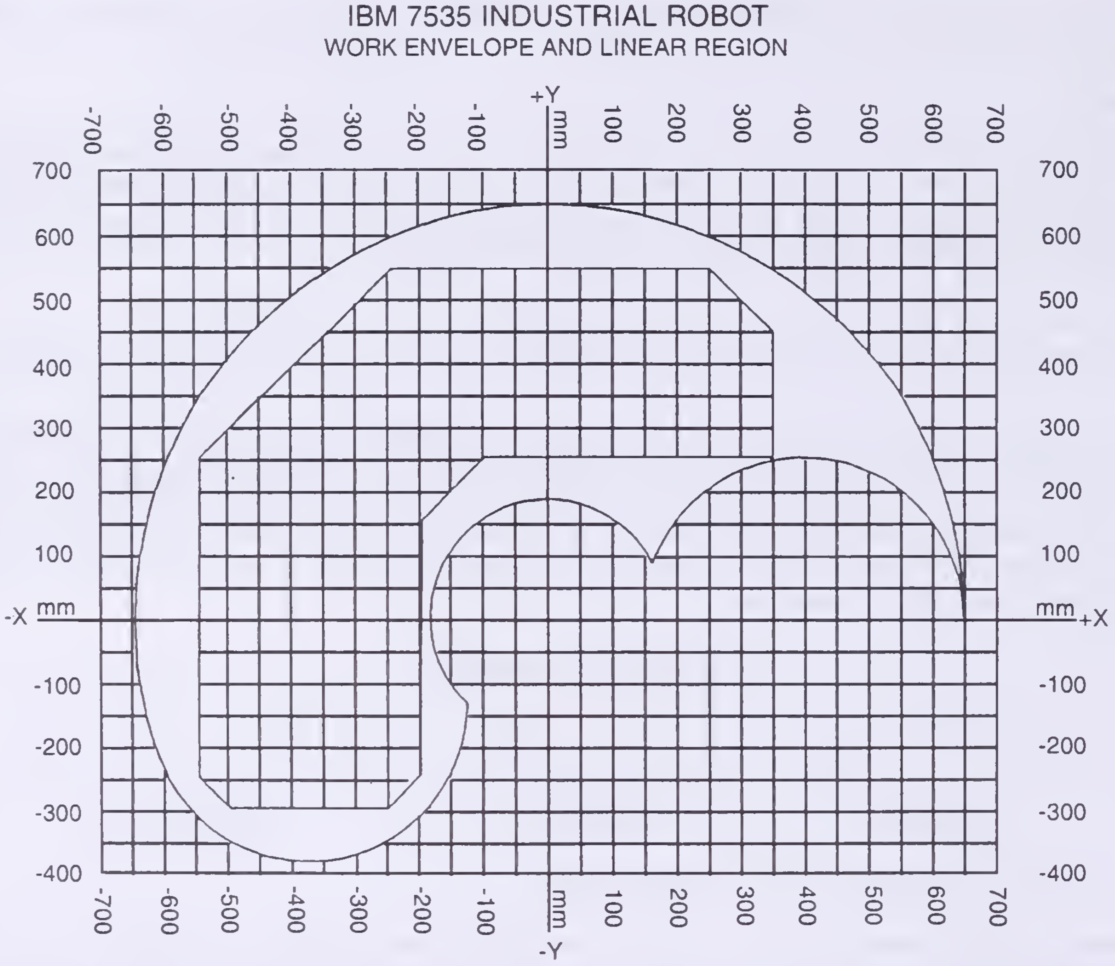
Equipment and Materials:

- IBM-compatible computer with mouse and VGA color display.
- Robotics Technology Programming Software package.
- Printer to produce a hard copy of your program.

Procedure:

1. Turn on the computer and start the AML programming software.
2. For this exercise you will be using a four axis IBM 7535 Robot. Check that the simulator is set for the 7535 by using the mouse to click on Config.

3. Before you begin to write the program, you must locate the seven points on the coordinate diagram of the work envelope in Figure 5-2. You must determine which of them are in the linear work region. Write a program to move the manipulator through the various points.



POINTS	X	Y	R
1.	300	400	0
2.	300	525	60
3.	-250	-250	120
4.	-550	-100	0
5.	-300	-125	-90
6.	-250	400	0
7.	350	250	100

Figure 5-2 IBM 7535 Industrial Robot work envelope.

4. Construct the program Use PAYLOAD, LINEAR, and ZONE statements, as well as the other AML statements you have previously learned. Change the PAYLOAD, LINEAR, and ZONE statements at least three times during the program. Use a DOWN, DELAY, and UP statement after the last PMOVE. Refer to the Help Menu in the programming software to assist you in writing the program.
5. Save the program as EXER5.AML.
6. Compile the program. If you have any problems, see your instructor.
7. After the program is successfully compiled, run it twice on the Simulator and print a timing report and a copy of the program.
8. Exit the AML program and turn off the computer.

Name ______________________________

Analysis:

1. Can you move from the home location when the robot is in the linear mode? Explain why.

2. When would you use a ZONE value of 1?

3. When would you use a ZONE value of 15?

4. What two things might happen if you were moving the robot arm at PAYLOAD(10) while it was carrying a part?

5. What happens to a PAYLOAD statement with a value of 10 that follows a LINEAR statement with a value of 1? What would happen if the LINEAR value were changed to 0?

Activity 6—Slide and Scale Exercise

Name ______________________________ Date ______________ Score __________

Objectives:

There are two sensor commands used in the AML Language, the WAITI and the WRITEO statements. The WAITI command instructs the robot controller to check a specified digital input (D/I) port for a value. The IBM 7535 robot has sixteen digital input ports, but the WAITI statement is only used with D/I ports 3-16. Digital inputs 1 and 2 are reserved for checking the Z axis movement. The value will be a 1 or 0.

If the value in the statement is a 0, the controller will wait for an open switch. A 1 value statement causes the controller to wait for a closed switch. The time limit parameter causes the controller to wait (in increments of .1 of a second) up to 25.5 seconds before indicating an error condition. The controller will wait indefinitely for the correct indication without setting an error lamp if the time limit is specified as 0. An example of a WAITI statement is shown below.

WAITI(6,1,7.5) --will wait up to 7.5 seconds for digital input #6 to become a closed-switch before setting the error lamp.

Another statement used in conjunction with digital inputs is the TESTI command. A TESTI command checks a digital input port for a "true" condition before transferring control to a line containing the specified label. The TESTI command can be used to control the flow of the program. It is similar to a *what if* statement used in other programming languages. If the condition is true, it moves to the line in the program containing the specified label. If the condition is false, the next statement that follows the TESTI statement is executed and transfer to the specified label does not occur. A TESTI statement is shown in the sample program that follows.

```
(Line #)
 START:
 TESTI (10, 1, STOP);        -- checks digital input #10 for closed
                             -- switch. If true, it goes to line 11
                             -- of the program which contains the label
                             -- STOP and moves to the home position. If
                             -- false, it executes the PMOVE in line 9.
                             -- labels are always followed by a colon(:)
                             -- never a semicolon(;).
     PMOVE (A);
     BRANCH (START);
     STOP:
     PMOVE (HOME);
```

The WRITEO command instructs the controller to open or close a digital output (D/O) port relay. A 0 value opens the relay. A 1 value closes the relay. The relay remains open or closed until another WRITEO command changes it. You will use WRITEO statements in Activity 8.

The purpose of this exercise is to provide you with the opportunity to write a program that incorporates the use of WAITI, TESTI, and BRANCH statements and labels. You will be using the IBM 7535 robot.

After completing this exercise, you will be able to:

- Δ Incorporate the use of WAITI, TESTI, and BRANCH statements and labels.
- Δ Checking specified digital input for a condition or waits for a specified value to occur.
- Δ Using BRANCH statements and labels for flow-of-control.

Equipment and Materials:

- IBM-compatible computer with mouse and VGA color display.
- Robotics Technology Programming Software package.
- Printer to produce a hard copy of your program.

Note: The illustrations in this activity are meant to give you an idea of the physical relationship between a robot and the supporting material referred to in the activity. The purpose of these exercises is to teach the basics of robot programming. This programming exercise will be done entirely on the computer without any additional laboratory equipment.

Procedure:

1. Turn on the computer and start the AML programming software.
2. Refer to Figures 6-1 and 6-2 for equipment layout for which the robot is being programmed. Configure the program for the IBM 7535 Robot.

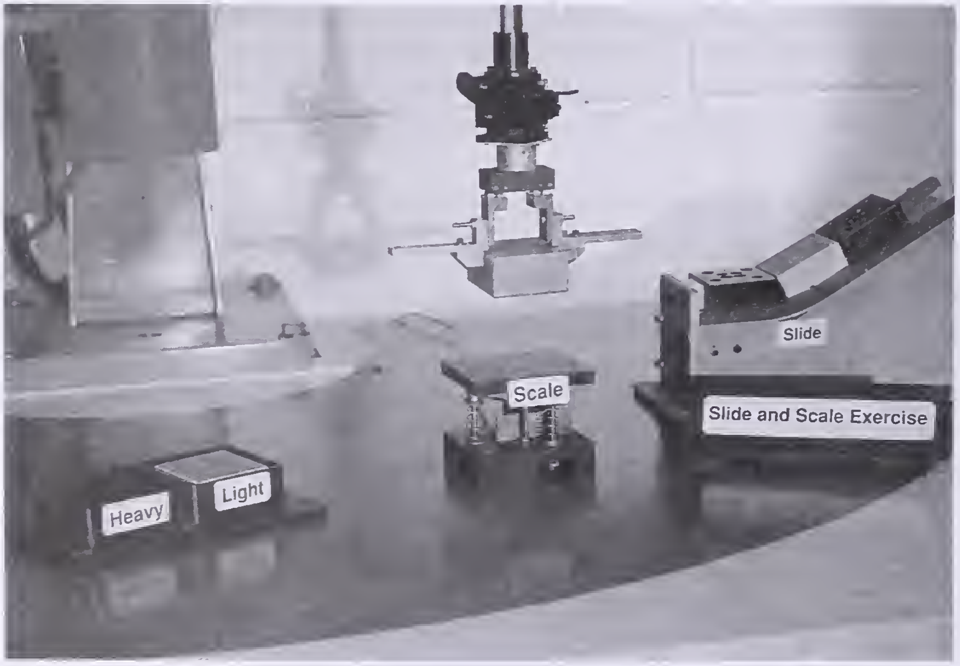


Figure 6-1 Equipment layout for Activity 6.

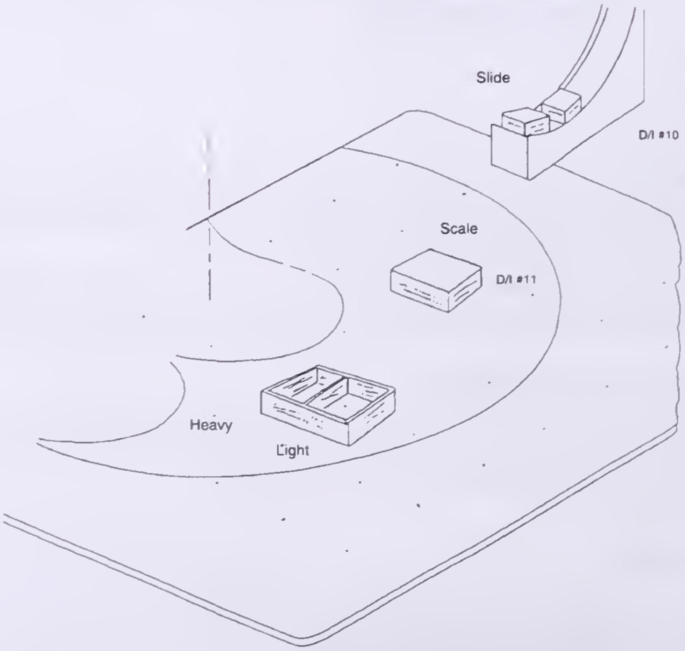


Figure 6-2 Plan view equipment layout for Activity 6.

Name ____

3. You will write a program to deal with parts having a substantial weight difference. This is a problem that occurs frequently in industry. A slide is equipped with a microswitch on its front edge which is used to indicate if a block is present. The slide is connected to digital input (D/I) #10. See Figure 6-3. Two types of blocks are to be delivered down a slide. Some the blocks are made of aluminum, while others are steel.

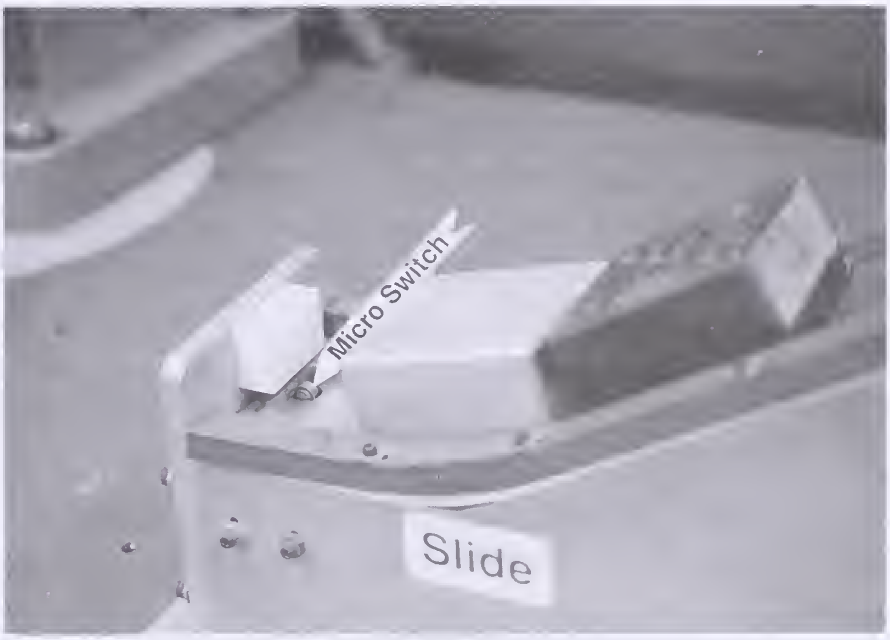


Figure 6-3 Microswitch for Digital Input #10.

4. You will program the robot manipulator to move to a pre-pickup point in front of the slide. A WAITI statement should be used to have the robot wait until a block is present before executing the next step in the program.
5. You will instruct the robot to move over the block on the end of the slide, (if one is detected) pick it up, and move back to the pre-pickup point. You should use a LINEAR movement between these two points so the robot arm can move straight in and out. This will keep the gripper from contacting the side of the slide. You may want to review Activity 5 for information concerning LINEAR movements.
6. You will program the robot to place the block on the scale and open its gripper. The scale is connected to digital input (D/I) #11 and is equipped with compression springs and a microswitch. See Figure 6-4 for the arrangement of the springs and the switch. A heavy block will cause the contacts in the switch to close. You should use a TESTI statement to determine if the block is light or heavy. After weighing, the robot picks up the block and drops it into the appropriate light or heavy compartment on the tray.

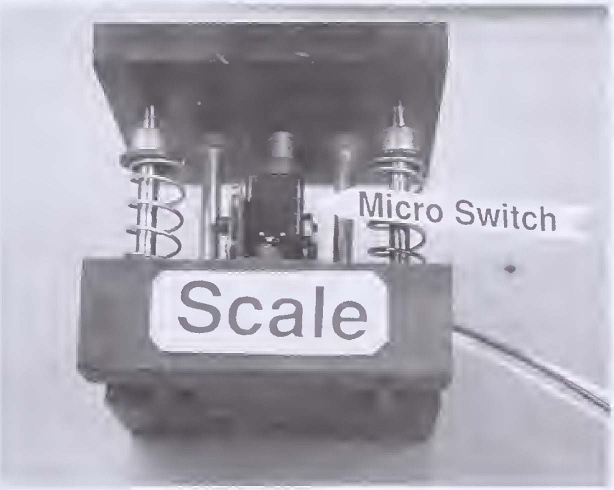


Figure 6-4 Microswitch for Digital Input #11.

7. If the block is light, you should use a BRANCH statement after the block is dropped to return to the start of the program. This prevents it from executing the next line of the program, which contains the label from the TESTI statement. If the block is heavy, the label in the TESTI statement will be executed. The label used in the TESTI statement cannot have the same exact name used for the point location in the Global Declaration Section.

Example

```
--------------------- Global Declaration Section---------------------
HEAVY:NEW PT(0.0, 0.0, 0.0);
TESTI (11, 1, HEAVY);      --incorrect same as point location
TESTI (11, 1, HEAVY_1);    -- this would be acceptable
```

8. On the next line after the label statement, instruct the robot to drop the block into the appropriate tray compartment. The END statement will reinitialize the program. Use the partial program example below to help you get started.

Partial Program Example

```
PRE_PICKUP:NEW PT(0.0, 0.0, 0.0);
SLIDE:NEW PT(0.0, 0.0, 0.0);
SCALE:NEW PT(0.0, 0.0, 0.0);
HEAVY:NEW PT(0.0, 0.0, 0.0);
LIGHT:NEW PT(0.0, 0.0, 0.0);
MAIN:SUBR;
----Write pickup and put down subroutines with parameters----

--------------------- Program ---------------------
START:
 WAITI (10, 1, 0);    -- waits indefinitely for switch to be made
 PMOVE (PRE_PICKUP);
 LINEAR (1);          --straightest possible move.
 PICKUP (SLIDE);
 PMOVE (PRE_PICKUP);
 LINEAR (0);          -- takes robot out of linear mode
```

9. Select Text/Editor and write your program. Save it as EXER6.AML.
10. Compile the program. If you have any problems, see your instructor.
11. After the program has been successfully compiled, run it on the Simulator. Running the program on the simulator will require input from you concerning the digital inputs. This will simulate the input from the microswitches in the scale and slide. Your instructor will give you the inputs needed for the program. Enter them as the program requests them. Run the simulation twice and print a timing report and hard copy of your program.
12. Exit the simulation program and turn off the computer.

Analysis:

1. What is the reason for using a WAITI statement in a program?

Name ____

2. If a WAITI statement has a time limit of eight seconds, what will happen if that time is exceeded?

3. What is the purpose of a BRANCH statement?

4. What is the function of a TESTI statement?

5. Write a TESTI statement that checks for an open-switch.

6. What would happen if a closed-switch was indicated during the TESTI check?

Activity 7—Path Exercise

Name ______________________________ Date ______________ Score __________

Objectives:

There are occasions when a subroutine or command must be repeated several times in a program. Many times the subroutines or commands are identical, except for the different values within them. Several of these subroutines or commands used in a program would make it quite long. AML employs the use of ITERATE statements to overcome this problem. The ITERATE statement repeats a subroutine or a command using the values provided in an ***aggregate.*** The aggregate contains the parameters to be executed in the subroutine. The ITERATE statement starts with the parameter on the left and moves toward the right. After the last parameter is executed, the program statement is executed. The following is the format of the ITERATE statement.

```
ITERATE ('command', <aggregate>, <aggregate>, .....);

ITERATE ('PMOVE' , POINTS);
```

Declaring Aggregate Constants:

Aggregate constants are declared in the Global Declaration Section of the program.

```
name:NEW <aggregate>;
POINTS:NEW <POINT1,POINT2>;
```

Aggregates are enclosed in angle brackets. The parameters that make up aggregates are separated by commas. Location positions, such as Point1 and Point2, must be declared before the Aggregate statement. The ITERATE command is used in conjunction with Aggregate statements to enable you to execute an AML command or subroutine with different values until all of the values are executed. In the following example, the PMOVE command is executed twice. Each time the PMOVE is executed, it takes on a new value. The locations for the moves are POINT1 and POINT2.

```
POINT1:NEW PT (100,200,0.0);
POINT2:NEW PT (50,100,0.0);
POINTS:NEW <POINT1,POINT2>;

MAIN:SUBR;
 ITERATE ('PMOVE',POINTS);
END;
```

After completing this exercise, you will be able to:

- Δ Develop a program that incorporates the use of aggregates statements and ITERATE commands to repeat an AML command with different values until all the values are executed.

Equipment and Materials:

- IBM-compatible computer with mouse and VGA color display.
- Robotics Technology Programming Software package.
- Printer to produce a hard copy of your program.

Procedure:

1. Turn on the computer and start the AML programming software. Configure the program for the IBM 7535 robot.
2. Refer to Figure 7-1 for the work envelope information for this exercise.

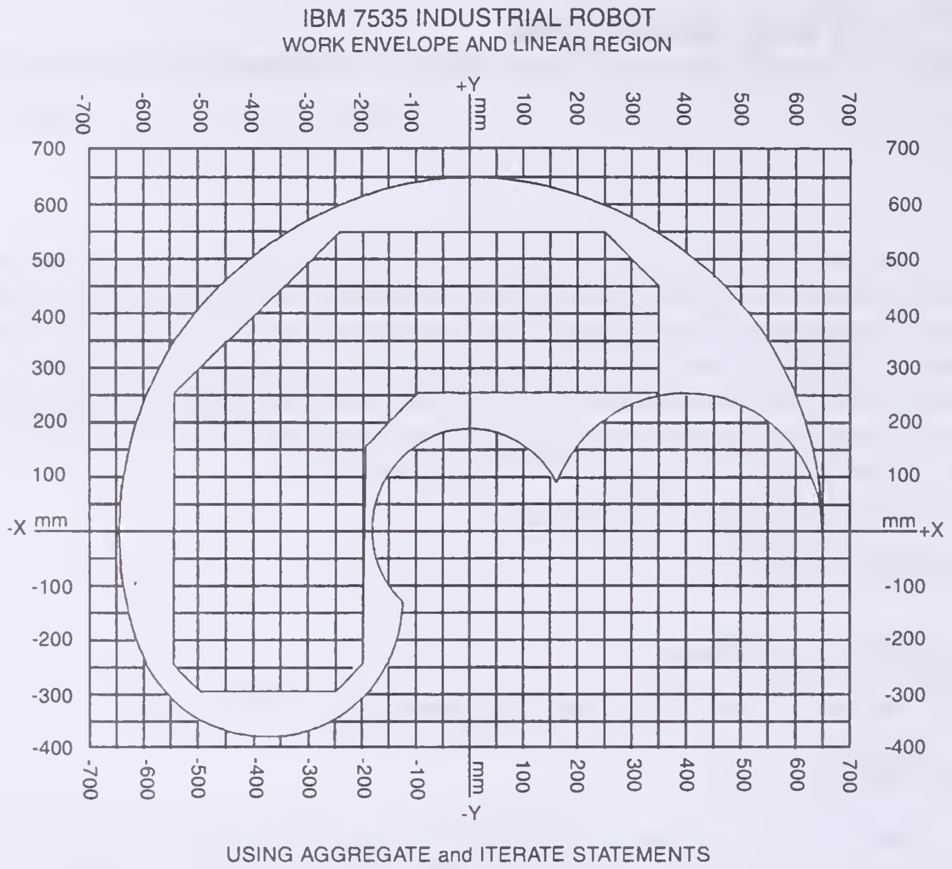

IBM 7535 INDUSTRIAL ROBOT
WORK ENVELOPE AND LINEAR REGION
+Y
mm
-700
-600
-500
-400
-300
-200
-100
100
200
300
400
500
600
700
-400
-300
-200
-100
-X
+X
mm
-Y
USING AGGREGATE and ITERATE STATEMENTS

Figure 7-1 IBM 7535 work envelope for path activity.

3. Start at the home position and move to an initial point in the work envelope.
4. Identify fifteen valid points in the work envelope.
5. Make up four paths from the initial point. Points can be used in more than one path (use aggregates to identify the points in each path).
6. Use four ITERATE statements to move along each path.
7. Change linearity twice (LINEAR).
8. Change speed for each path (PAYLOAD).
9. Use UP and DOWN statements at the end of each path.
10. At the end of the last path send the robot to the home position.
11. Save as EXER7.AML.
12. Compile the program. If you have problems, see your instructor.
13. After the program has been successfully compiled, run it twice on the Simulator and print a timing report. Select Text/Editor and print a copy of your program.

14 Exit the AML program and turn off the computer.

Name ______________________________

Analysis:

1. Write a ITERATE statement for a PMOVE command.

2. What is the advantage of using ITERATE and aggregate statements?

____

3. Summarize the purpose of the following program.

```
PT1:NEW PT (100,200,0.0);
PT2:NEW PT (-200,300,0.0);
PATH:NEW <PT1,PT2>;
MAIN:SUBR;
ITERATE ('PMOVE',PATH);
END;
```

____

4. Can a LINEAR statement be executed as the robot moves from the Home position? If it cannot, explain.

____

____

____

____

____

Activity 8—Using Digital Outputs to Control Different Z Levels

Name ______________________________ Date ______________ Score __________

Objectives:

Pickup and putdown locations in an industrial setting often have different elevations or Z levels. On the Z axis of the IBM 7535 Robot, there are only two positions–fully up or fully down. However, by using a proximity sensor, two digital outputs (D/O) ports, and blocks of different thickness connected to air cylinders, we would be able to stop the robot at three different downward positions.

Study the equipment layout for this activity. You will notice that Station #1 and the first step on Station #2 are at different levels. When the robot is picking up or putting pegs down at the lowest step of station #2, the Z axis is fully extended. In Figure 8-1, the air cylinders are retracted and the proximity sensor rests on the stop.

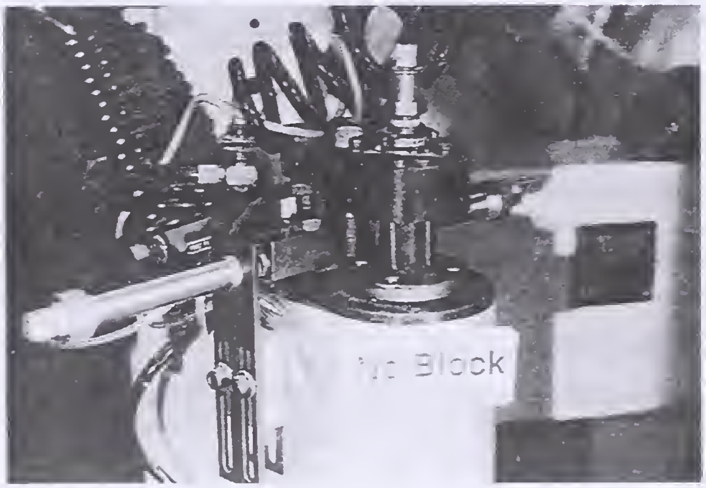


Figure 8-1 Both cylinders retracted.

If you are picking up or putting pegs down at the middle step, you would program the robot to activate the air cylinder with the small block. Figure 8-2 shows the air cylinders with the small block engaged and the proximity sensor resting on it.

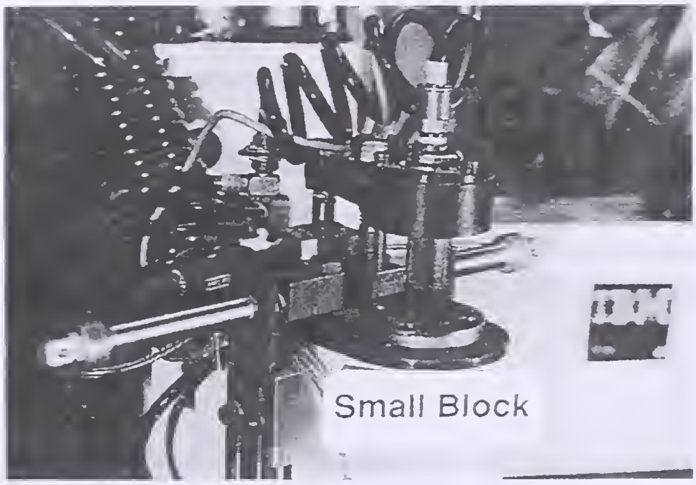


Figure 8-2 Small block engaged.

If you want to pick up or put down pegs at the top step, you would program the robot to activate the air cylinder with the large block. Figure 8-3 shows the air cylinders with the large block engaged and the proximity sensor resting on it.

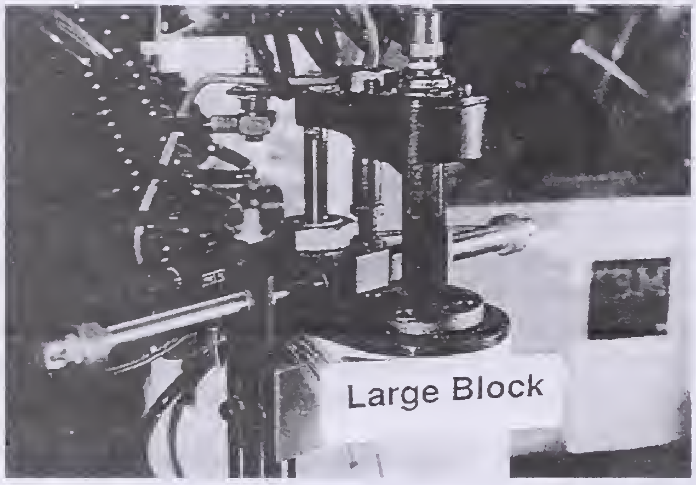


Figure 8-3 Large block engaged.

Using WRITEO Commands to Control Cylinders

The WRITEO command instructs the controller to open or close a digital output (D/O) port relay. Remember, there are sixteen digital output ports, with 1 and 2 reserved for the gripper and Z axis movement. A 0 value opens the relay. A 1 value closes the relay. The relay remains open or closed until another WRITEO command changes it. An example of a WRITEO statement follows.

```
WRITEO (8,1) -- digital output #8 relay is closed.
```

If a control circuit for a conveyer were connected to digital output port #8, you could program the robot controller to turn the conveyer's drive motor on or off. In this exercise, you will use WRITEO commands to stop the robot at different locations along the Z axis.

After completing this exercise, you will be able to:

- Δ Write user subroutines that use WRITEO commands to control digital outputs.
- Δ Write a program and call each user subroutine at the appropriate time to stop the robot at three different locations along the Z axis.

Equipment and Materials:

- IBM-compatible computer with mouse and VGA color display.
- Robotics Technology Programming Software package.
- Printer to produce a hard copy of your program.

Note: The illustrations in this activity are meant to give you an idea of the physical relationship between a robot and the supporting material referred to in the activity. The purpose of these exercises is to teach the basics of robot programming. This programming exercise will be done entirely on the computer without any additional laboratory equipment.

Procedure:

1. Turn on the computer and start the AML programming software. Configure the software for the IBM 7535 robot.
2. Refer to Figures 8-4 and 8-5 for layout of equipment for this exercise.

Name ____

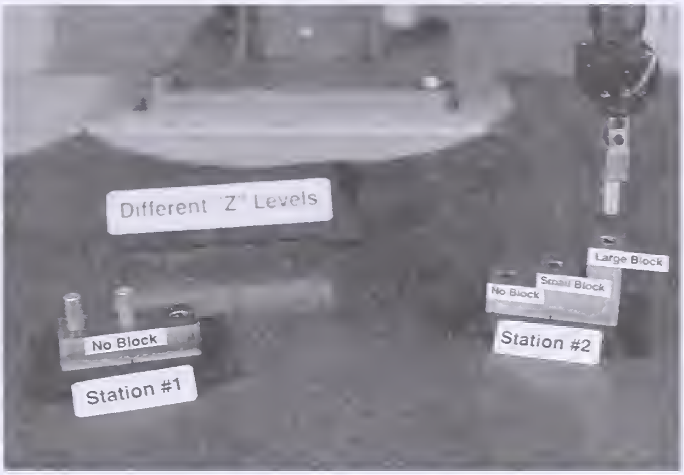


Figure 8-4 Equipment layout for Activity 8.

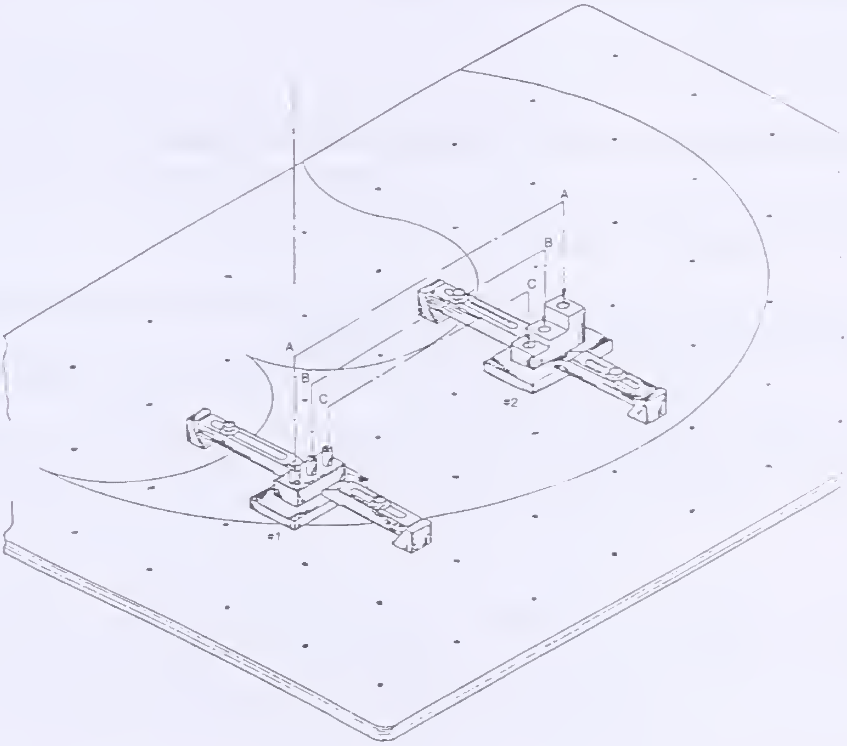


Figure 8-5 Plan view layout of equipment for Activity 8.

The Z axis is equipped with two air cylinders and a proximity sensor to control the travel of the Z axis. You will be using digital outputs #4 and #6 to control the air cylinders. The small block cylinder is connected to D/O #4. The cylinder with the large block is connected to D/O #6.

3. Use the following user subroutines.

```
PICKUP:SUBR;
PUTDOWN:SUBR;
NOBLOCK:SUBR;
SMALLBLOCK:SUBR;
LARGEBLOCK:SUBR;
```

4. Study the following example. Use it as a model for your Largeblock subroutine.

```
LARGEBLOCK:SUBR;
 WRITEO (4,0); -- retracts smallblock cylinder
 WRITEO (6,1); --activates largeblock cylinder
END;
```

5. Write a program to move the three pegs located at station #1 to station #2 and back to station #1. The following program example involves picking up a peg at location A1 and putting it down at the highest step, A2.

```
NOBLOCK;                    -- both cylinders disengaged
 PICKUP (A1);               -- pick up peg at station #1, location A
 LARGEBLOCK ;               -- cylinder with large block engaged
 PUTDOWN (A2);              -- put down peg at station #2, location A
END;
```

6. Save program as EXER8.AML.
7. Compile the program. If you have any problems, see your instructor.
8. After the program has been successfully compiled, run it twice on the Simulator and print a timing report and a hard copy of your program.
9. Exit the simulation program and turn off the computer.

Analysis:

1. Write a WRITEO command to turn digital output (D/O) #10 and #11 on.
2. Write a WRITEO command to turn digital output (D/O) #10 and #11 off.
3. Write a user subroutine that turns D/O #11 off and D/O #10 on.
4. How many digital outputs and inputs are available for your use?
5. If you use a WRITEO command to turn a relay on, how do you turn it off?

Activity 9—Using ZMove Commands

Name ______________________________ Date ________________ Score __________

Objectives:

The program you wrote in Activity 8 used digital outputs to stop the IBM 7535 Robot at different Z levels. When using a robot that does not have a servo-controlled Z axis, this is one means of controlling its movement. If a robot with a servo-controlled Z axis (such as the IBM 7545 Robot) is available, you can program a greater number of stopping points along that axis. The IBM 7545 Robot has a Z travel distance in millimeters of 0 mm (fully retracted) to -75 mm (fully extended).

In this exercise, you will revise the program you wrote for Activity 8 using ZMOVE commands to stop the IBM 7545 Robot at different Z levels. Since you will be using the ZMOVE command, all the UP and DOWN statements, and the Noblock, Smallblock, and Largeblock subroutines will not be used in the program.

After completing this exercise, you will be able to:

- Δ Call up and revise an existing program using the ZMOVE command to control movement along the IBM 7545 Robot's Z axis.

Equipment and Materials:

- IBM-compatible computer with mouse and VGA color display.
- Robotics Technology Programming Software package.
- Printer to produce a hard copy of your program.

Procedure:

1. Turn on the computer and start the AML programming software.
2. Before you begin constructing your program select Config from the Main Menu and set the robot configuration for the **IBM 7545 Robot.** Type 4 and press ENTER to save the configuration.
3. Go to the Text/Editor and open the file you created for Activity 8, EXER8.AML. Change the point locations so they include a Z level location of 0 while maintaining the same X, Y, and R locations you taught in the previous exercise. The following is an example of a point location with a Z level of 0.

```
                       X      Y      Z    R
POINT1:NEW PT (-100.0, 200.0, 0.0, 150);
```

4. Remove all the UP and DOWN statements and Noblock, Smallblock, and Largeblock subrouties from the program. Revise the Pickup and Putdown user subroutines.

   Use the following example as a model for your revised user subroutines.

Example

```
PICKUP:SUBR(PLACE,LENGTH);
  PMOVE(PLACE);
  RELEASE;
  DELAY(.5);
  ZMOVE(LENGTH);
  GRASP;
  DELAY(.5);
  ZMOVE(0);
END;
```

5. Use the Teach program to enter the following Z levels.

- Station #1 -50 mm
- Station #2, lower step -50 mm
- Station #2, middle step -37 mm
- Station #2, upper step -24 mm

6. Revise the remainder of the program, using ZMOVE commands instead of UP and DOWN statements.

Example

```
------------------- Program Execution Begins---------------------
ZMOVE(0):                  -- Z axis retracted
PICKUP(A1,-50);            -- move to point A1, Z level is -50 mm
PUTDOWN(A2,-24);           -- move to point A2, Z level is -24 mm
PICKUP(B1,-50);            -- move to point B1, Z level is -50 mm
PUTDOWN(B2,-37);           -- move to point B2, Z level is -37 mm
END;
```

7. Save the revised program as EXER9.AML.
8. If you have not changed the software configuration to the IBM 7545 Robot, do so now.
9. Compile the program. If you have any problems, see your instructor.
10. After the program has been successfully compiled, run it on the Simulator. When the prompt asks if you want to change the model number, change it to **7545** and ENTER. Run the simulation twice and print a timing report and a copy of your program.
11. Exit the simulation program and turn off the computer.

Analysis:

1. Why are you able to use ZMOVE statements with the IBM 7545 Robot, but not the IBM 7535 Robot?

____

____

2. Write a user pickup subroutine that employs formal parameters for the PMOVE and the ZMOVE.

Name ______________________________________

3. What is the total Z axis travel distance (in millimeters) for the IBM 7545 Robot?

____

4. What does a ZMOVE (0) mean?

____

5. What are the four coordinates used in the point locations in the Global Declaration Section of the program?

____

____

____

____

Activity 10—Palletizing Exercise

Name ______________________________ Date ________________ Score __________

Objectives:

A pallet is a common type of container used to hold and move parts. In industry, robots are often used to pick up parts from an incoming feeder and place them onto a pallet. A diagram of a pallet that could be used is shown in Figure 10-1.

Notice that the holes in the pallet are arranged in a pattern. This allows for a specified number of parts as well as locations for all parts by row and column position. The AML programming language has a keyword called STATIC PALLET that allows for efficient programming of palletizing operations. The following is an example of the format used in AML to call a pallet. The keyword STATIC PALLET defines a "name" to be a pallet. In this example, the name would be PALLET_1 .

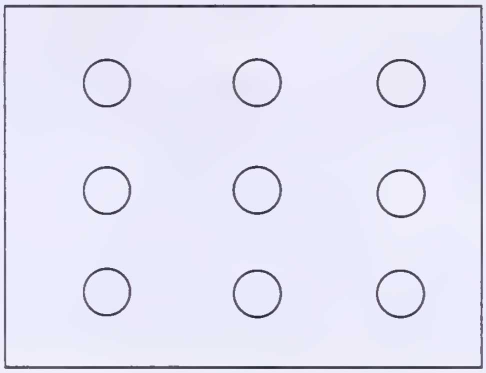


Figure 10-1 Typical parts pallet.

```
PALLET_1:STATIC PALLET (LL,LR,UR,PPR,PARTS);
```

The parameters within the parenthesis are defined as:

LL = lower left part location
LR = lower right part location
UR = upper right part location
PPR = number of parts per row
PARTS = total number of parts in the pallet

In this exercise, you will write a program that will use both the palletizing commands and the STATIC COUNTER commands used in Activity 4 to move pegs from Pallet #1 to Pallet #2 and back again.

After completing this exercise, you will be able to:

- Δ Write a program that uses palletizing commands and statements to move pegs from one pallet to another.
- Δ Use a STATIC COUNTER to perform the palletizing operation four times.

Equipment and Materials:

- IBM-compatible computer with mouse and VGA color display.
- Robotics Technology Programming Software package.
- Printer to produce a hard copy of your program.

Note: The illustrations in this activity are meant to give you an idea of the physical relationship between a robot and the supporting material referred to in the activity. The purpose of these exercises is to teach the basics of robot programming. This programming exercise will be done entirely on the computer without any additional laboratory equipment.

Procedure:

1. Turn on the computer and start the AML programming software. Configure the software for the IBM 7535 Robot.
2. Refer to Figures 10-2 and 10-3 for equipment layout for this exercise.
3. You will use the following commands and keywords in addition to those you have used in Activities 2 through 9. Refer to the Help Menu in the programming software for additional assistance in writing your program.

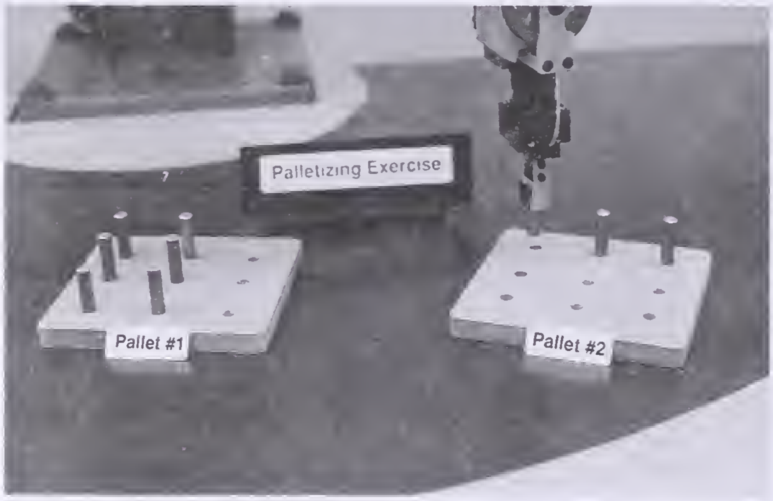


Figure 10-2 Equipment layout for Activity 10.

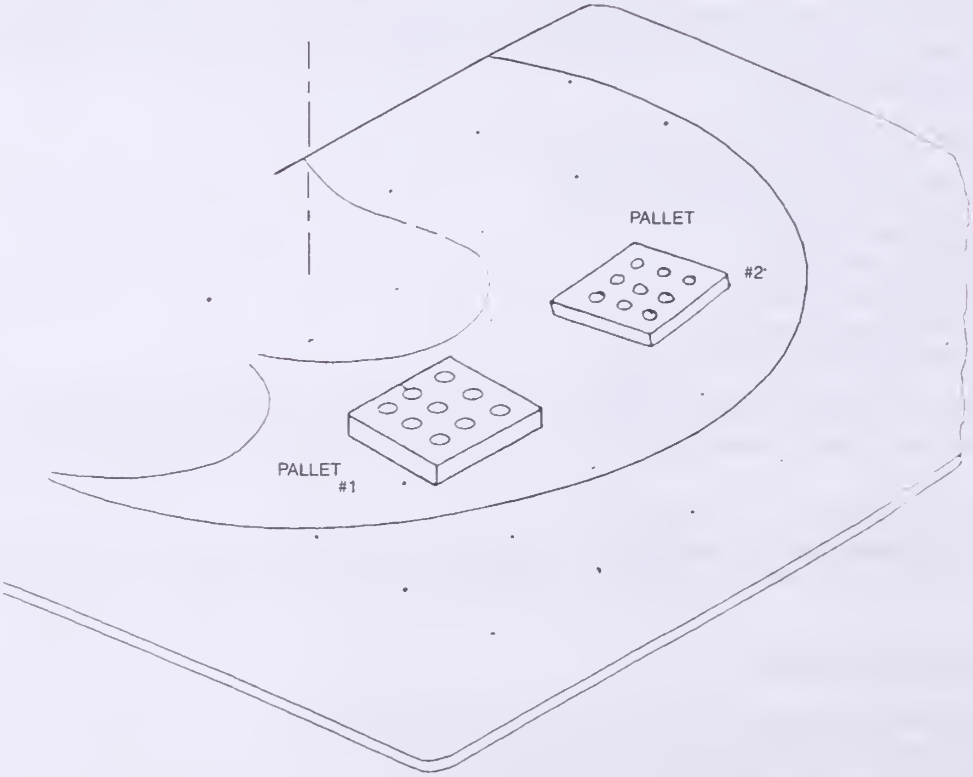


Figure 10-3 Plan view layout of equipment for Activity 10.

Name ____

AML Commands and Keywords

STATIC -- this keyword reserves controller storage for a counter or pallet. Study the example shown below.

```
name:STATIC COUNTER;
name:STATIC PALLET;
```

GETPART (name) -- this palletizing command moves on the "named" pallet. It is similar to a PMOVE.
NEXTPART (name) -- this palletizing command increases the current part count by one.
PREVPART (name) -- this palletizing command decreases the current part count by one.
SETPART (name,value) -- this command sets the "named" pallet's current part to a specified value.
TESTP (name,value,label) -- this palletizing command compares the pallet's current part indicator to a value. If the value matches, the program uses a BRANCH statement to go to the line containing the statement label. If the value does not match, the program executes the next statement below the TESTP statement. The name used in this command is the same name used in the STATIC PALLET statement.

Study this example program to learn how to use the palletizing commands. Your program will command a robot to remove all the parts from one pallet and place them at another location in the work envelope. In an actual work cell, the location could be a machining operation. Once the machine work was complete, a second robot might remove the part and take it to another workstation.

```
------------------ Global Declaration Statement------------------
LL1:NEW: PT(125.00, 350.00, 0.0);              -- Location of part in lower
                                               -- left corner of the pallet
LR1:NEW: PT(300.00, 350.00, 0.0);              -- Location of part in lower
                                               -- right corner of the pallet
UR1:NEW PT(300.00, 500.00, 0.0)                -- Location of part in upper
                                               -- right corner of the pallet
PPR:NEW (8);                                   -- Number of parts per row in pallet
PARTS:NEW (32);                                -- Total number of parts in the pallet
WKPOINT:NEW PT(250,300,0);                     -- Point out in the work space
HOME:NEW PT(650, 0, 0);                        -- Home point

--------------------- Declares the static pallet --------------------
 PALLET1:STATIC PALLET(LL1,LR1,UR1,PPR,PARTS) -- Identify pallet

--------------------------Main Program --------------------------
MYPROG:SUBR;                                   -- Main program subroutine begins here
PICKUP:SUBR;                                   -- Code for pickup subroutine here
END;
PUTDOWN:SUBR;                                  -- Code for putdown subroutine here
END;

---------------------Initialize part count ---------------------
SETPART (PALLET1,0);

----------------------Set up a programming loop----------------------
LOOP:
GETPART(PALLET1);                              -- Get a part from pallet #1, location #1 (LL1)
 PICKUP;                                       -- Call pickup subroutine
 PMOVE(WKPOINT);                               -- Move to work point
 PUTDOWN;                                      -- Call putdown subroutine
 TESTP(PALLET1,PARTS,DONE);                    -- Test to see if pallet is empty
 NEXTPART(PALLET1);                            -- Increase part count by one so robot will
                                               -- move to location #2
BRANCH(LOOP);                                  -- Pallet still has parts
DONE:
 PMOVE(HOME);                                  -- Finished with pallet
END;                                           -- Program ends
```

5. Declare PALLET1, PALLET2, and COUNTER.
6. Declare the main user subroutine.
7. Write Pickup and Putdown user subroutines as needed.
8. Initialize the pallets and counter.
9. Write user subroutines as needed to move the pegs from pallet #1 to pallet #2 and back to pallet #1. You will use a counter to repeat this four times. You will have to use a DELAY statement whenever the gripper is opened or closed. Be sure to use a TESTP statement to see if pallets are empty.
10. Send the robot to the home position when finished.
11. Save the program as EXER10.AML.
12. Compile the program. If you have any problems, see your instructor.
13. After the program has been successfully compiled, run it twice on the Simulator and print a timing report and a hard copy of your program.
14. Exit the simulation program and turn off the computer.

Analysis:

1. What is the correct syntax for identifying the STATIC PALLET in the Global Declaration section?

   ____

2. What changes would have to be made to have the parts moved six times?

   ____

   ____

3. If you did not have the palletizing commands and statements, how would you write a program to move the nine pins over and back?

   ____

   ____

4. What is the purpose of the TESTP statement?

   ____

5. What is the purpose of the BRANCH statement in this program?

   ____

Activity 11—Fuse Continuity Test

Name ____ Date __________________ Score ___________

Objectives:

The programming activities you have completed gave you opportunities to write programs that perform tasks very similar to those found in industry. In writing your programs, you have used most of the AML keywords and commands. The only ones you have not used are the BREAKPOINT and DPMOVE commands. The BREAKPOINT command is used so the robot operator can interrupt and restart the application at some convenient point in the program, rather than restarting the program from its beginning. The DPMOVE is a delta or incremental move. DPMOVE differs from PMOVE in that the PMOVE moves the manipulator to a specified location, while DPMOVE moves the robot manipulator a specified distance.

Example of a DPMOVE

The robot's arm is located at the coordinates of X=300, Y=425 and R=80 in the work envelope. A part is needed at coordinates X=320, Y=450, and R=20. The delta move for X is 20 which is the difference between 300 and 320. The delta move for Y is 25, which is the difference between 425 and 450. The change in roll is -60 which is the difference between 80 and 20. The command in the program appears as:

```
DPMOVE(<20,25,-60>);
```

This programming exercise does not require use of the DPMOVE. You can try to use the DPMOVE command on your own, however. If you feel comfortable using the DPMOVE, try using it in your program. Refer to the Help menu in the programming software for additional assistance.

As you reflect back on your programming experience, you realize the activities became more complex as you progressed through them. This activity will provide you with an opportunity to take the knowledge you gained from the previous activities and apply it to a more complex programming application.

After completion of this exercise, you will be able to:

- Δ Take the knowledge gained from your programming experiences and apply it to more complex programming situations.

Equipment and Materials:

- IBM-compatible computer with mouse and VGA color display.
- Robotics Technology Programming Software package.
- Printer to produce a hard copy of your program.

Note: The illustrations in this activity are meant to give you an idea of the physical relationship between a robot and the supporting material referred to in the activity. The purpose of these exercises is to teach the basics of robot programming. This programming exercise will be done entirely on the computer without any additional laboratory equipment.

Procedure:

1. Turn on the computer and start the AML programming software. Configure the software for the IBM 7535 robot.
2. Refer to Figures 11-1 and 11-2 for equipment layout for this exercise. Study the layout very carefully.
3. In addition to the various user subroutines, you will be required to use digital outputs, digital inputs, ZONE, LINEAR, PAYLOAD, TESTI, WAITI, and BRANCH statements to accomplish the task.
4. You will use the following digital input ports in your program.

D/I #3 -- sensor on feeder tube A1, use WAITI statement.
D/I #4 -- test block fuse check, use TESTI statement.
D/I #5 -- sensor on storage tube B1, use TESTI statement.
D/I #6 -- sensor on feeder tube C1, use TESTI statement.

5. Use the following digital output ports in your program. Refer to Figures 11-3 and 11-4 to see the resulting wrist position.

D/O #3 -- flips wrist up and down, use WRITEO statement.
D/O #8 -- turns on light to warn operator, use WRITEO statement.

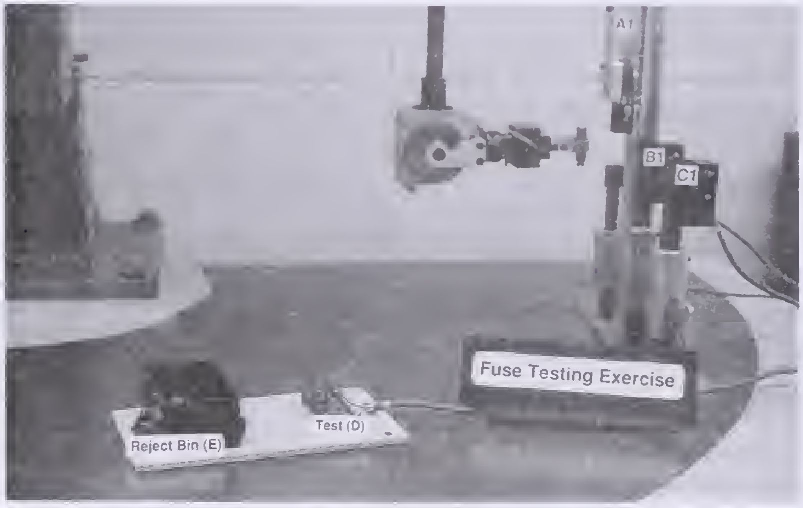


Figure 11-1 Equipment layout for Activity 11.

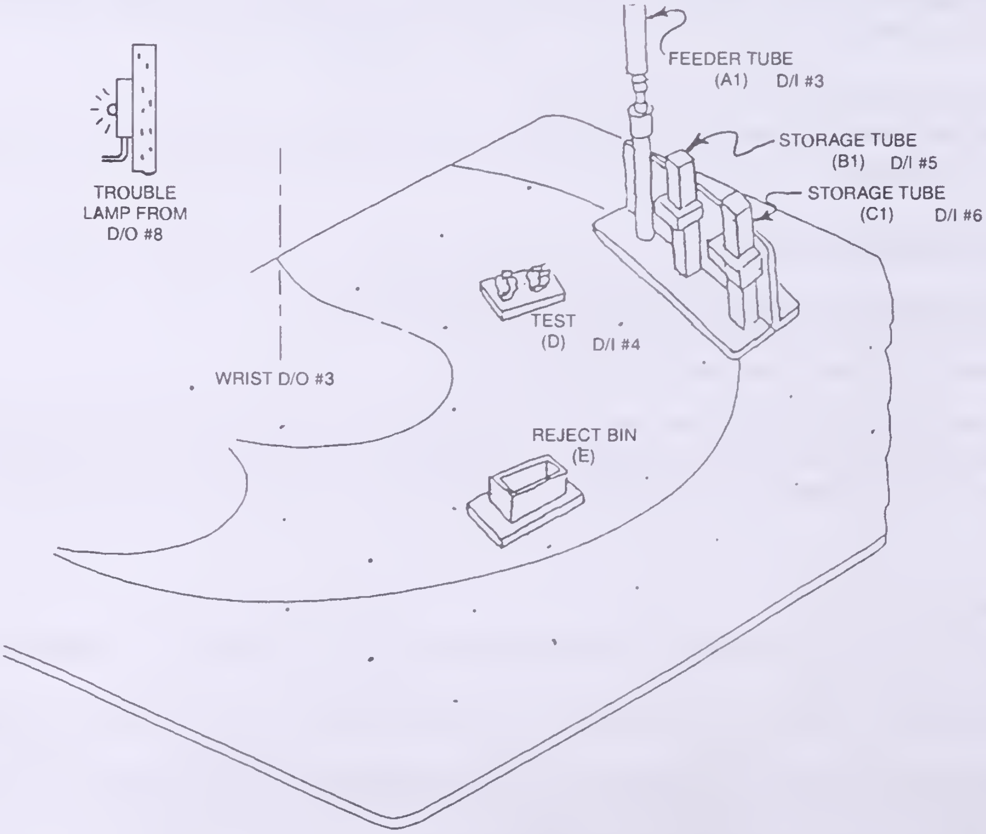


Figure 11-2 Plan view layout of equipment for Activity 11.

Name ____

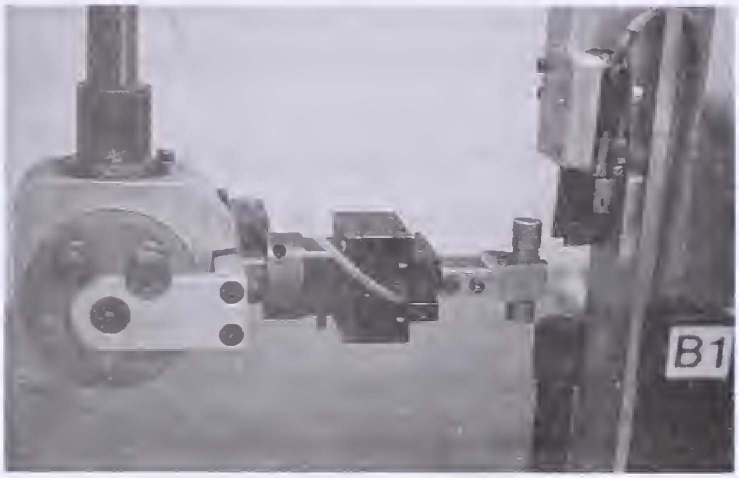


Figure 11-3 Wrist in the flipped up position (D/O #3).

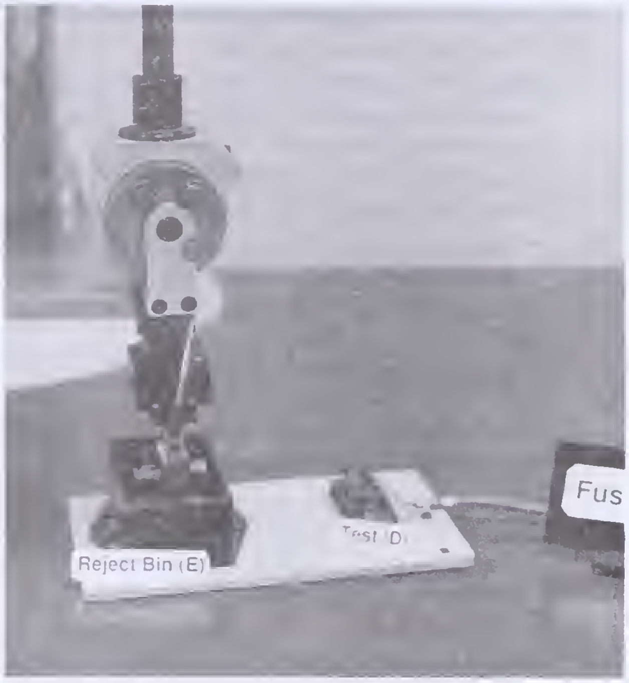


Figure 11-4 Wrist in the flipped down position (D/O #3).

6. Write a program that will command a robot to pick up a fuse from feeder tube A1 and move it to station D for testing. The program should deposit the fuse at station B1, C1, or E depending on the results of the test. Write a user subroutine to place the fuse in storage tube C1 if storage tube B1 is full. You will also write a user subroutine to turn on a light connected to digital output #8 if storage C1 is full.

7. To simplify your programming, point positions and user subroutine names are provided. The basic layout of the program is as follows.

```
----------------------- Global Statements -----------------------
A: NEW PT(-305.00, 68.05, -80.72)        -- linear point in front of point (A1)
B: NEW PT(-300.00, 181.45, -80.72)       -- linear point in front of point (B1)
C: NEW PT(-305.00, 303.60, -80.72)       -- linear point in front of point (C1)
A1: NEW PT(-503.65, 68.05, -80.72)       -- feed tube pickup point
B1: NEW PT(-507.65, 181.45, -80.72)      -- first storage tube point
C1: NEW PT(-498.20, 303.60, -80.72)      -- second storage tube point
D: NEW PT(-216.25, 255.45, -90.00)       -- test point for good fuses
E: NEW PT(-262.95, 393.95, -1.08)        -- reject bin location point
```

```
MAIN:SUBR;
PICKUP_A:SUBR(PLACE);          -- picks fuse from feed tube
END;
PUTDOWN:SUBR(PLACE);           -- places fuse on test block (D) or reject
                               -- bin (E)
END;
PUT_BC:SUBR(PLACE);            -- put fuse in storage tube A1 or B1
END;
PICKUP_D:SUBR(PLACE);          -- picks fuse from test block (D)
END;

--------------------- Program Execution Begins ---------------------
START:
WAITI (3,1, 20);               -- waits 20 seconds to see if part is present
UP;
ZONE(1);                       -- sets for most precise point location
PAYLOAD(5);                    -- sets speed
PMOVE(A);                      -- moves to point in front of feeder tube
LINEAR(5);                     -- sets for linear mode (straight move)
WRITEO(3,1);                   -- flips wrist up to 90 degrees
DELAY(2.0);                    -- delays 2.0 seconds for wrist to flip up
PICKUP_A(A1);                  -- move in and grasps fuse in feeder tube
PMOVE (A);                     -- moves back to point A
LINEAR(0);                     -- takes program out of linear mode
WRITEO(3,0);                   -- flips wrist down
DELAY(2.0);                    -- delays 2.0 seconds for wrist to flip down
PUTDOWN(D);                    -- places fuse on test block
TESTI(4, 1, B_TUBE);           -- checks to see if fuse is good
                               -- write code to dispose of bad fuse in
                               -- reject bin and branch back to start
B_TUBE:
TESTI (5, 1, C_TUBE);          -- checks to see if storage tube B is full,
                               -- if not write code to place fuse in tube
                               -- B.
C_TUBE:
TESTI (6, 1, STOP);            -- checks to see if storage tube C is full,
                               -- if not write code to place fuse in tube C.
STOP:
WRITEO (8,1);                  -- turns on warning light to tell operator to empty
                               -- storage tubes
END;
```

Remember to use LINEAR, and WRITEO statements for digital output #3 with a value of 1 or 0 to flip wrist up and down, and branch back to start after returning to points B and C.

8. Save the program as EXER11.AML.
9. Compile the program. If you have problems, see your instructor.
10. After the program has been successfully compiled, run it twice on the Simulator. Print a timing report and a copy of your program.
11. Exit the simulation program and turn off the computer.

Name ______________________________

Analysis:

1. What is the reason for using a LINEAR statement to move from A to A1, B to B1, and C to C1?

____

2. What is the purpose of the TESTI statement in this exercise?

____

____

____

____

____

____

____

____

3. Would a WAITI statement with a time value of 0 wait for an digital input to close? If so, how long would it wait?

____

4. What is the purpose of the WRITEO statement in this exercise?

____

____

5. Write a WRITEO statement that could be used to flip the wrist up and down.

6. What is the purpose of the BRANCH statement in this exercise?

____

____

____

____

Activity 12—Basic Electrical Symbols

Name ______________________ Date ______________ Score __________

Objectives:

Working with robotic systems requires the ability to read and recognize electrical schematic symbols. Electrical schematics are used to maintain, adjust and repair robotic systems and controllers. Many of these symbols will be used in the activities that follow.

In this activity, you should study and learn to recognize the basic symbols shown in Figure 12-1. You may demonstrate your understanding by completing the self-test on electrical symbols.

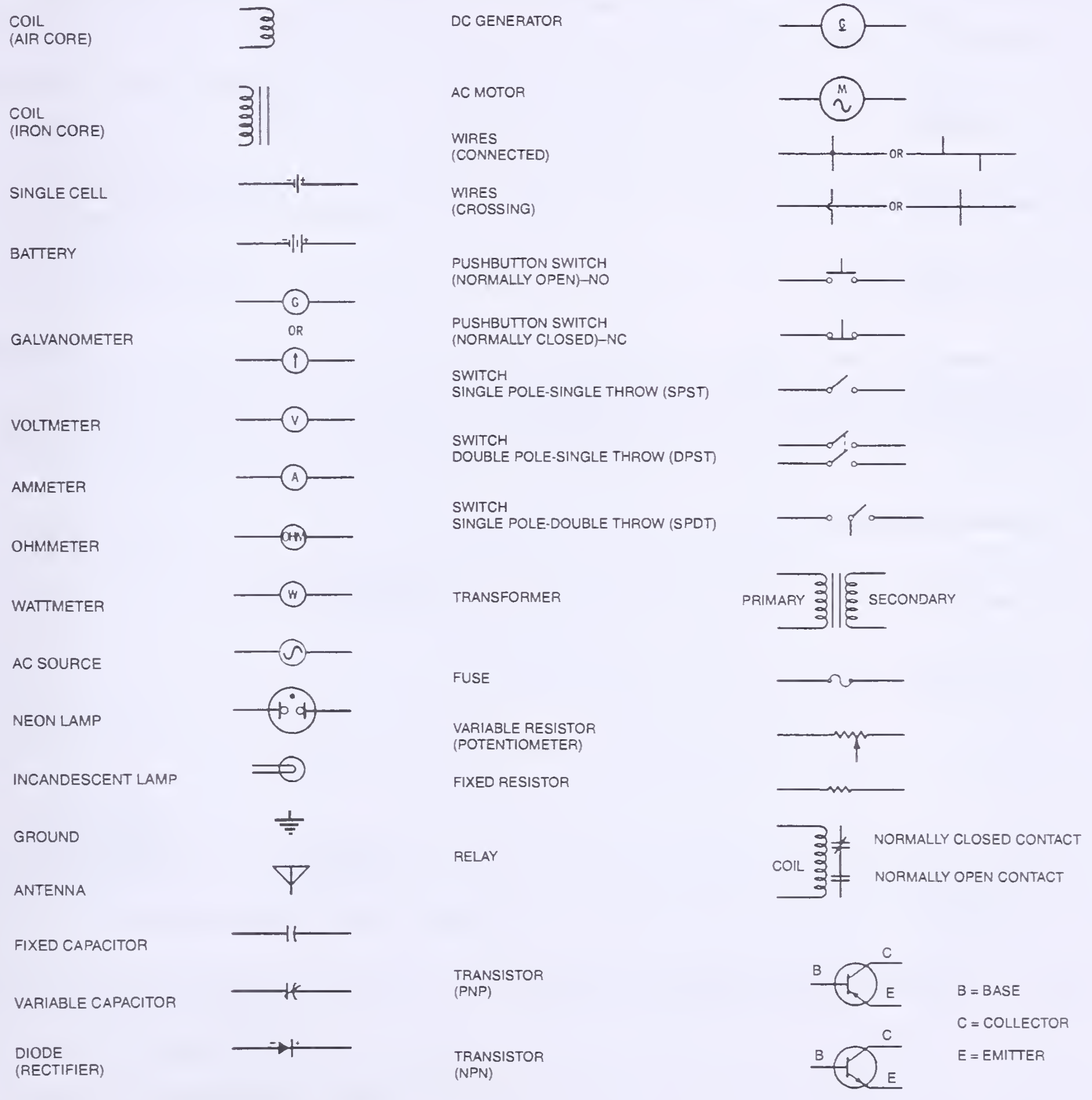
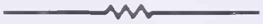
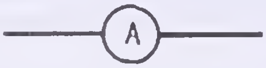


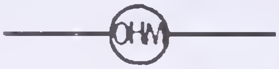
Figure 12-1 Electrical schematic symbols.

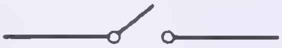
Analysis:

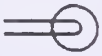
Without looking at the symbols in Figure 12-1, identify each of the symbols that follow. Place the correct response in the space provided.

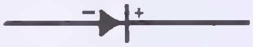
1. 

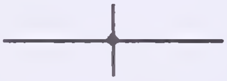
2. 

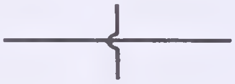
3. 

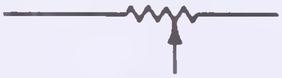
4. 

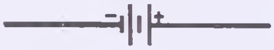
5. 

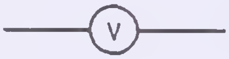
6. 

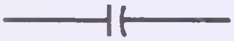
7. 

8. 

9. 

10. 

11. 

12. 

Activity 13—Electrical Components, Equipment, and Symbols

Name ______________________________ Date ______________ Score ________

Objectives:

Basic to the study of any technical subject is the understanding of the language and symbols used. The study of robotics technology is dependent on the graphic language of electrical diagrams. Various components, equipment, and symbols are used. You should become familiar with the graphic symbols used in electrical diagrams and learn to recognize the symbols used for common electrical devices.

Equipment and Materials:

- Meter.
- SPST switch.
- Potentiometer (any value).
- Connecting wires for circuit board.
- 6v battery.
- 6v lamp with socket.

Procedure:

1. The wires you will use in this activity are paths for the movement of electrons. Wires may be connected to each other at almost any angle or may cross each other without being connected. The graphic symbols representing these connecting wires, called conductors, are illustrated in Figure 13-1.

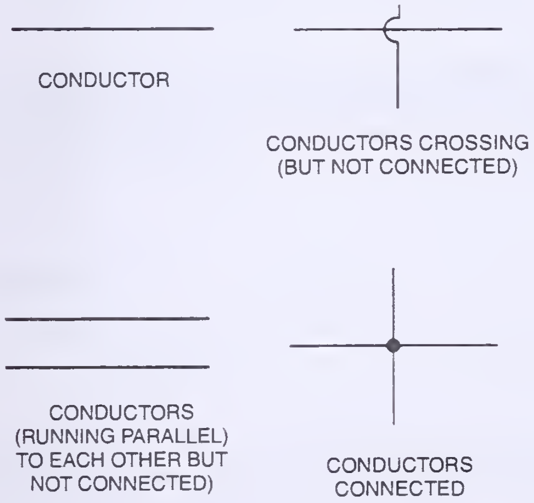

CONDUCTOR
CONDUCTORS CROSSING (BUT NOT CONNECTED)
CONDUCTORS (RUNNING PARALLEL) TO EACH OTHER BUT NOT CONNECTED)
CONDUCTORS CONNECTED

Figure 13-1 Different schematic symbols for conductors.

2. In the illustration of Figure 13-2, how many times do conductors cross each other and how many times are conductors connected to each other?

Conductors cross each other __________ times.

Conductors are connected to each other __________ times.

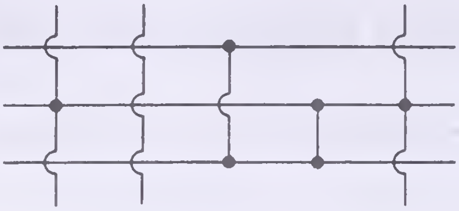


Figure 13-2 Various conductor in a schematic.

3. A single-pole, single-throw (SPST) switch is a device used to allow current to flow when closed, or on, and interrupt the flow of current when open, or off. A switch is used to turn the light in a room on and off. The symbols representing the SPST switch in its two conditions, on and off, are illustrated in Figure 13-3.

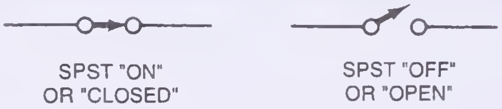


Figure 13-3 Schematic,symbols for a single-pole, single-throw switch.

4. Fixed resistors are used frequently to control current flow. The symbol for a fixed resistor is illustrated in Figure 13-4.

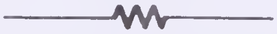


Figure 13-4 Fixed resistor.

5. A light bulb or lamp is a common component used in flashlights and other devices to produce light. The symbol of an incandescent lamp is shown in Figure 13-5.

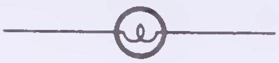


Figure 13-5 Incandescent lamp.

6. A potentiometer, or pot, is a resistive component that can be adjusted to control current flow. A potentiometer is used to increase or decree the volume of a radio or TV set. The illustrations of Figure 13-6 represent the schematic symbols for a potentiometer. Notice that the center connection of the potentiometer is designated by an arrow and represent the adjustable portion of the device.

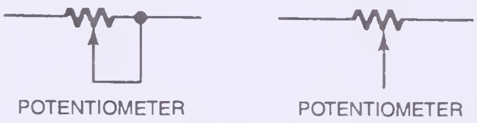


Figure 13-6 Schematic symbols for a potentiometer.

7. The 6v battery is a chemical source of electrical energy that causes current to flow through conductors, resistors, and other component. The symbol of Figure 13-7 is used for a battery. Note that one of the connectors of the battery is labeled with a + sign and the other is labeled with a – sign. It is always important to observe how a battery is connected to a circuit.

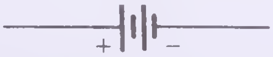


Figure 13-7 Battery.

8. Use your circuit board or trainer unit to set up the *circuit* shown in Figure 13-8. Several types of circuit boards and trainers that may be used for your experiment are shown in Figure 13-9. You should study the layout of the board you are using. Be sure that you connect this circuit and the others you will construct properly. You should become very familiar with the use of a circuit board. For most circuit boards, it is necessary to cut wire of the

Name ______________________________________

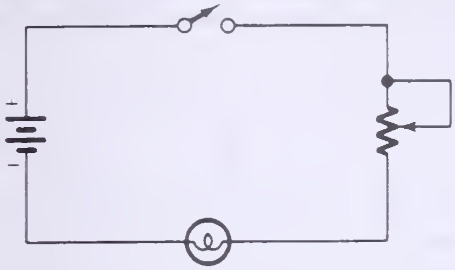


Figure 13-8 Series circuit with potentiometer.

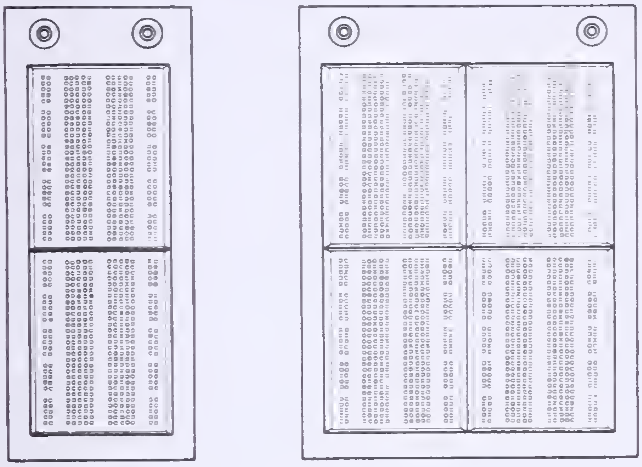


Figure 13-9 Circuit trainer board.

proper diameter to various sizes and strip about 1/4 in. of insulation from both ends. The wires are then used to make circuit connections. The switch and potentiometer should have wires soldered to their terminals about 2 in. long for connecting to the circuit board. They will be used for other experiments.

9. Complete the circuit connection using your board. Close the SPST switch and adjust the potentiometer from its maximum counterclockwise position to its maximum clockwise position. What happens to the lamp? If the circuit is constructed properly the lamp should get brighter and then dimmer as the potentiometer is adjusted.
10. Adjust the potentiometer until the lamp is at its brightest and open the SPST switch. What happens to the lamp?

Analysis:

1. Draw the symbols for the indicated components in the space below.

Fixed Resistor Potentiometer Open SPST Switch

2. Draw the symbols for conductors in the space below.

Conductors Crossing Conductors Connected

3. Draw the symbol for a battery, placing the positive (plus) sign and the negative sign (minus) at the proper sides of the symbol.

4. Draw the symbol for a lamp.

Activity 14—Basic Electrical Problem Solving

Name ______________________________ Date ______________ Score __________

Objectives:

Basic electrical problems are often encountered in any area which involves electrical control systems. Robotics is no exception. The most basic problems in electrical systems involve Ohm's law. Ohm's law is a mathematical formula which explains the relationship between voltage, current, and resistance. This relationship must be understood before electrical concepts are meaningful. In this activity, you will complete some practical problems by applying Ohm's law. Refer to Figure 14-1 for assistance.

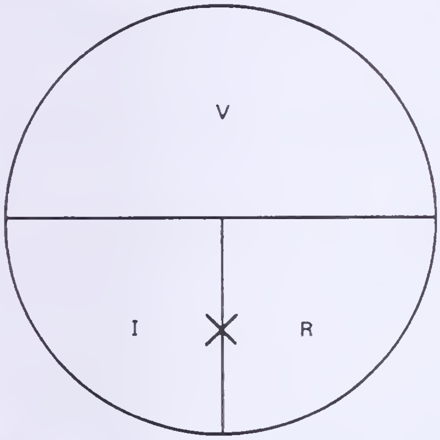


Figure 14-1 Ohm's law circle: *V,* voltage; *I,* current; *R,* resistance. To use the circle, cover the value you want to find and read the other values a they appear in the formula: $V = I \times R$, $I = V/R$, $R = V/I$.

Analysis:

1. A doorbell requires 0.2 ampere of current in order to ring. The voltage supplied to the bell is 120 volts. What is its resistance?

   R = __________ ohms.

2. A relay used to control a motor is rated at 25 ohms resistance. What voltage is required to operate the relay if it draws a current of 0.25 ampere?

   V = __________ volts.

3. An automobile battery supplies a current of 7.5 amperes to a headlamp with a resistance of 0.84 ohm. Find the voltage delivered by the battery.

   V = __________ volts.

4. What voltage is needed to light a lamp if the current required is 2 amperes and the resistance of the lamp is 50 ohms?

   V = __________ volts.

5. If the resistance of a radio receiver circuit is 240 ohms and it draws a current of 0.6 ampere, what voltage is needed?

   V = __________ volts.

6. A television circuit draws 0.15 ampere of current. The operating voltage is 120 volts. What is the resistance of the circuit?

   R = __________ ohms.

7. The resistance of the motor windings of an electric vacuum cleaner is 20 ohms. If the voltage is 120 volts, find the current drawn.

   I = __________ amperes.

8. The coil of a relay carries 0.05 ampere when operated from a 50 volt source. Find its resistance.

   R = __________ ohms.

9. How much current is drawn from a 12 volt battery when operating an automobile horn of 8 ohms resistance?

   I = __________ amperes.

10. Find the resistance of an automobile starting motor if it draws 90 amperes from the 12 volt battery.

    R = __________ ohms.

11. What current is drawn by a 5000-ohm electric clock when operated from a 120 volt line?

    I = __________ amperes.

12. Find the current drawn by a 50-ohm toaster from a 120 volt line.

    I = __________ amperes.

Activity 15—Electrical Meters

Name ______________________________ Date ______________ Score ________

Objectives:

Electrical meters are used to measure voltage, current, resistance, and other electrical quantities. There are two general types of electrical meters—analog and digital. Analog meters have a hand or pointer that moves according to the amount of the quantity being measured. Digital meters display numbers indicating the amount of the quantity that is measured. Measurements are made in many types of electronic circuits. You should learn the proper procedure for measuring resistance, voltage, and current. These are the three most common electrical measurements.

Measuring Resistance

Many important electrical tests can be made by measuring resistance. Resistance is opposition to the flow of current in an electrical circuit. The current that flows in a circuit depends upon the amount of resistance in that circuit. You should learn to measure resistance in an electrical circuit by using a meter.

A multimeter is used to measure resistance, voltage, or current. The type of measurement can be changed by adjusting the **function-select switch** to the desired measurement. Figure 15-1 shows the controls of a common type of multimeter. This type of meter is also called an analog meter.

Notice that the function-select switch is in the center of the meter. Also notice that part of the range is for measuring ohms or resistance. The ohms measurement is divided into four ranges: × 1, × 10, × 1000, and × 100,000. This is called a multirange multimeter. Most multimeters are very similar to Figure 15-1. The meter is adjusted to any of the four positions for measuring resistance. The test leads used with the meter are ordinarily black and red. These colors are used to help identify which lead is the positive or negative side.

Measuring Voltage

Voltage is applied to electrical equipment to cause it to operate. It is important to be able to measure voltage in order to check the operation of equipment. Many electrical problems develop due to either too much or too little voltage being applied to the equipment. A multimeter is used to measure voltage in an electrical circuit. The controls of a multimeter are shown in Figure 15-1. The voltage ranges shown are 2.5, 10, 25, 100, and 500v. When the function-select switch is adjusted to 500v on the dc volts range, the meter measures up to 500v. The same is true for the other ranges of dc voltage. The voltage value of each range is the maximum voltage that may be measured on that range.

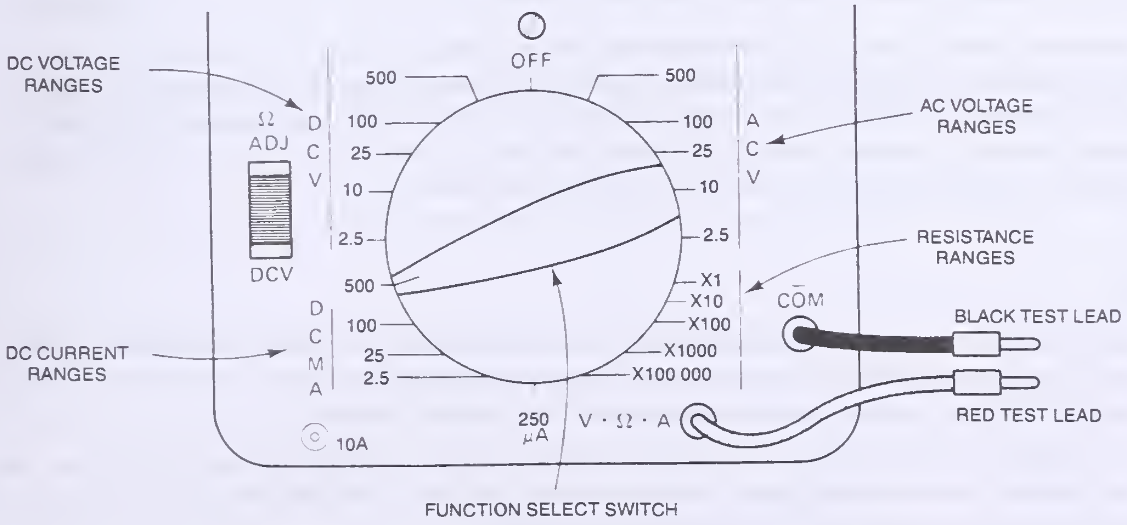


Figure 15-1 Controls of a typical multimeter.

When making voltage measurements, adjust the function-select switch to the highest range of dc voltage. Connect the red and black test leads to the meter. The red test lead should be put into the jack labeled V-Ω-A. The black test lead should be put into the jack labeled –COM.

It is easy to become familiar with the part of the meter's scale that is used to measure dc voltage. Refer to the scale of Figure 15-2. Notice that below the ohms scale is the dc voltage scale. This scale is usually black. Notice that there are three dc voltage scales: 0 to 2.5v, 0 to 5v, and 0 to 10v. All dc voltages are measured using one of these scales. Notice that each of the dc voltage ranges on the function-select switch corresponds to a number on the right side of the meter scale or a number that can be easily multiplied or divided by 10 to equal the number on the function switch.

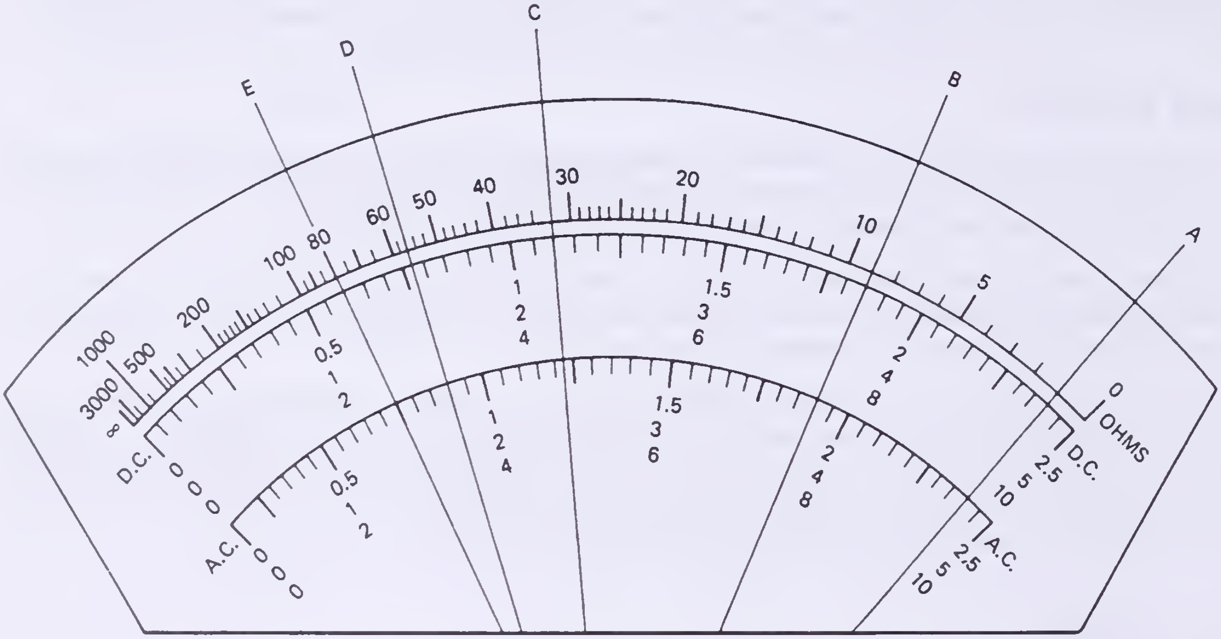


Figure 15-2 Analog meter scale.

Measuring Current

Current flows through a complete electrical circuit when voltage is applied. Many important tests are made by measuring current flow in an electrical circuit. The current values in an electrical circuit depend on the amount of resistance in the circuit. Learning to use an ammeter to measure current in an electrical circuit is very important.

To measure the current through a circuit, R_1, first make sure that no voltage is applied to the circuit. Current is measured in **series** with the circuit. Remove the wire at the point of the measurement. Set the meter to the highest current range. Connect the negative test lead to the most negative point and the positive test lead nearest the positive power source terminal. Now apply voltage to the circuit. Adjust the meter, if necessary, to a lower range to get an accurate current reading. Then read the current value on the scale of the meter.

Digital Meters

With the use of digital electronics in robots, digital meters are becoming common place. They employ numerical readouts to simplify the measurement process and to make more accurate measurements. Digital meters rely on the operation of digital circuitry to produce a numerical readout of the measured quantity.

The readout of a digital meter is designed to transform electric signals into numerical data. Both letter and number readouts are available, as are seven-segment, discrete-number, and bar-matrix displays. Each method has a device designed to change electric energy into light energy on the display.

Name ____

Analysis:

Obtain the meter that you will be using for completing your activities. Study the meter and answer each of the following questions.

1. What company manufactured the meter?

   ____

2. What is the model number of the meter?

   ____

3. The meter will measure up to __________ A of dc.
4. True or False: Ohms-adjust control is used each time the resistance range is changed.

   ____

5. To measure dc current greater that 1 A, the range switch is placed in the __________ position.
6. For measuring current in a circuit, the meter should be connected in (series or parallel) __________.
7. For measuring voltage, the meter should be connected in (series or parallel) __________.
8. To measure 18 mA of current, the range switch should be placed in the __________ position.
9. To measure 10 μA of current, the range switch should be placed in the __________ range.
10. To measure resistance, the red test lead must be placed in the jack marked __________ and the black test lead in the jack marked __________.
11. True or False: Polarity must be observed when measuring ac voltage.

    ____

12. True or False: Polarity is not important when measuring resistance.

    ____

13. Up to __________v can be measured with the meter.
14. For measuring a resistor valued at 10Ω, the __________ range should be used.
15. True or False: Polarity must be observed when measuring dc.

    ____

16. True or False: It is correct to measure the resistance of a circuit with voltage applied.

    ____

17 True or False: When measuring an unknown value of voltage, one should start at the highest scale and work down to the correct scale.

    ____

18. True or False: Meters should be handled with care and safety.

    ____

Meter Exercises:

Instructions: Refer to the figure of a meter scale (Figure 15-2) and fill in the blanks with the values that correspond to the pointer location.

Ohms Range	*A*	*B*	*C*	*D*	*E*
R x 1	(1)________	(6)________	(11)________	(16)________	(21)________
R x 10	(2)________	(7)________	(12)________	(17)________	(22)________
R x 100	(3)________	(8)________	(13)________	(18)________	(23)________
R x 1000	(4)________	(9)________	(14)________	(19)________	(24)________
R x 10,000	(5)________	(10)________	(15)________	(20)________	(25)________

Dc volts Range	*A*	*B*	*C*	*D*	*E*
2.5v dc	(26)________	(32)________	(38)________	(44)________	(50)________
10v dc	(27)________	(33)________	(39)________	(45)________	(51)________
50v dc	(28)________	(34)________	(40)________	(46)________	(52)________
250v dc	(29)________	(35)________	(41)________	(47)________	(53)________
500v dc	(30)________	(36)________	(42)________	(48)________	(54)________
1000v dc	(31)________	(37)________	(43)________	(49)________	(55)________

Dc amps Range	*A*	*B*	*C*	*D*	*E*
10a	(56)________	(64)________	(72)________	(80)________	(88)________
2.5a	(57)________	(65)________	(73)________	(81)________	(89)________
500mA	(58)________	(66)________	(74)________	(82)________	(90)________
100mA	(59)________	(67)________	(75)________	(83)________	(91)________
50mA	(60)________	(68)________	(76)________	(84)________	(92)________
10mA	(61)________	(69)________	(77)________	(85)________	(93)________
2.5mA	(62)________	(70)________	(78)________	(86)________	(94)________
250µA	(63)________	(71)________	(79)________	(87)________	(95)________

Activity 16—Industrial Electronic Symbols

Name ______________________________ Date ________________ Score __________

Objectives:

There are certain electronic symbols that are fundamental to industrial control systems. The majority of the symbols selected for this activity are used frequently in control circuits. You should be familiar with each symbol as a basis of understanding schematic diagrams.

In this activity, you should review the representative symbols (Figure 16-1) and demonstrate your understanding by completing the analysis.

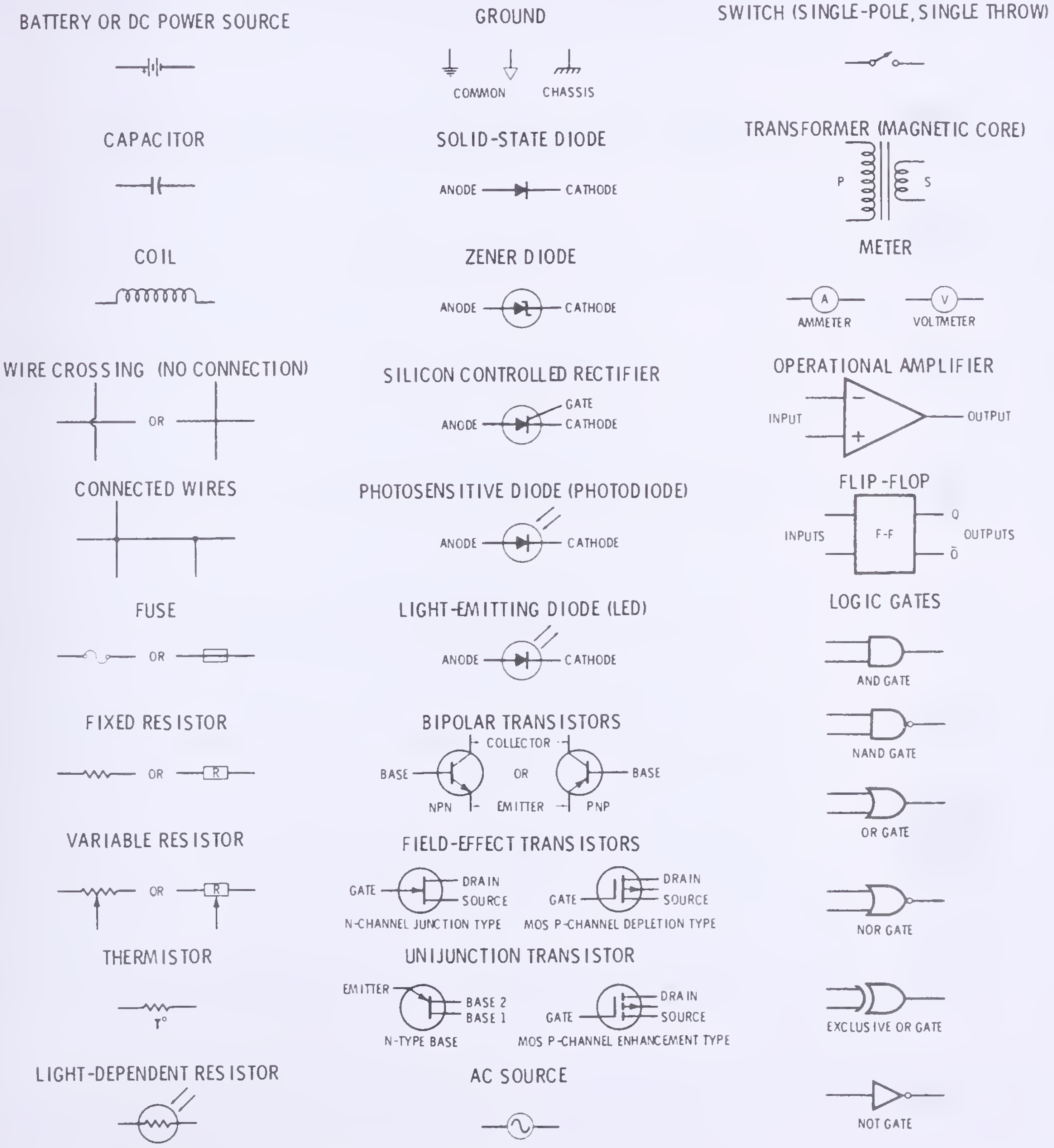
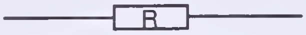


Figure 16-1 Frequently used industrial electronic symbols.

Analysis:

Without looking at the symbols in Figure 16-1, identify each of the following symbols. Place the correct response in the space provided.

1. 

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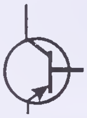
2. 
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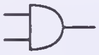
3. 
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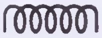
4. 
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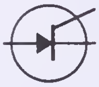
5. 
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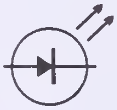
6. 
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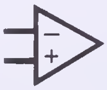
7. 

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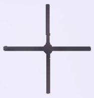
8. 
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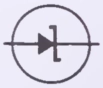
9. 
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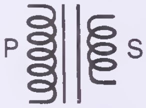
10. 

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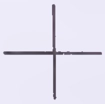
11. 
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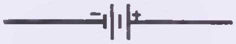
12. 
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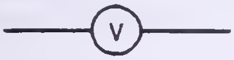
13. 

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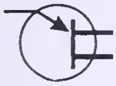
14. 
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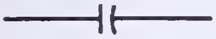
15. 
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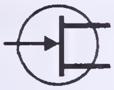
16. 
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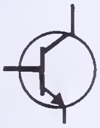
17. 
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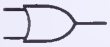
18. 
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Activity 17—Soldering and Terminal Connections

Name ______________________ Date ______________ Score __________

Objectives:

In this activity, you will demonstrate your skill in three important exercises: (1) soldering, (2) desoldering, and (3) terminal connection. An understanding of the proper soldering and terminal connection techniques is needed by technicians who design, service, or repair industrial equipment, including robots.

Equipment and Materials:

- Soldering iron—25 to 50 W.
- Desoldering tool.
- Solder.
- No. 22 insulated wire—3″ length.
- Printed circuit board.
- Component mounting strip.
- Resistor.
- Wire stripper.
- Side-cutting pliers.
- Needle-nose pliers.
- "Solderless" connector and wire.
- Crimping tool.

Safety:

Exercise caution while soldering. Use protective eyewear and clothing during soldering operations.

Procedure:

Section A. Soldering Iron Preparation and Component Mounting

1. Allow the soldering iron to heat to its operating temperature.
2. Apply a small amount of solder to tin the tip of the iron.
3. Obtain a component-mounting strip and a resistor from your instructor.
4. Using proper soldering techniques, solder the resistor onto the component mounting strip.

   Instructor's Approval: ______________________

Section B. Printed Circuit Board Soldering

1. Obtain a printed circuit (pc) board and a 3″ length of No. 22 insulated wire.
2. Place the wire near the holes in the pc board where you intend to solder it to determine the length of wire required.
3. Strip 3/8″ to 1/2″ of insulation from one end of the wire with the wire stripper.
4. Cut off any excess wire and strip the insulation off the other end of the wire. The wire should lie flat on the pc board when soldered.
5. Using the proper soldering techniques, solder both ends of the wire to the pc board terminals.

   Instructor's Approval: ______________________

Section C. Printed Circuit Board Desoldering

1. Obtain a desoldering tool.
2. Allow the desoldering tool to heat to its operating temperature.
3. Using the proper desoldering techniques, remove the piece of wire from the pc board without damaging the conductive strips on the pc board.

Instructor's Approval: ______________________________

Section D. Terminal Connection Installation

1. Obtain a "solderless" terminal connector crimping tool and a length of insulated wire from your instructor.
2. Strip enough insulation from the wire so that the terminal connector fits properly.
3. Use the crimping tool to fasten the terminal connector to the wire.

Instructor's Approval: ______________________________

Activity 18—Troubleshooting and Testing

Name ______________________________ Date ______________ Score __________

The lab activities included in this book provide an opportunity to practice troubleshooting and testing electronic circuits, devices, and systems. Troubleshooting and testing procedures may be accomplished while performing the lab activities. Emphasis is placed on understanding circuit operation, safety, and the proper use of test equipment. If the technician understands how the circuit, device, or system functions and knows how to use test equipment, troubleshooting and testing are relatively easy to accomplish. This is true for the simplest type of circuit or for more complex systems.

Objectives:

Upon completion of this activity, you should be able to outline basic troubleshooting procedures, test devices and circuits using the correct procedure, and find the defective part or circuit by using a "common sense" approach.

Troubleshooting is a systematic process by which malfunctions are traced and repaired. A technician should be able to systematically locate and repair many malfunctions. For effective troubleshooting, you should have a practical understanding of the type of system that is being repaired. With this basic knowledge of operation and some test equipment, you should be able to perform many repair jobs.

Electrical motors are commonly used with robotic systems. Some of the following instruments may be used to make various tests on the motor: (1) tachometer—speed test; (2) megger—insulation test; (3) multimeter—resistance, current, and voltage test; (4) growler—wound armature test; and (5) motor dynamometer analysis unit—speed vs torque test. You should check with the instructor on the use of some of this equipment as your troubleshooting progresses.

After you complete this activity, you will be able to systematically test and repair a motor of any type. Many parts of the procedure listed may not be applicable to your particular troubleshooting job. However, try to follow most of the listed steps and complete the analysis.

Equipment and Materials:

- Motor that does not function properly.
- Multimeter.
- Growler (optional).
- Megger (optional).
- Dynamometer (optional).
- Tachometer (optional).

Procedure:

1. Examine the external features of the motor you are to troubleshoot.
2. Find the motor nameplate and record the information called for below. If not available, indicate so in the blank.

Manufacturing Co. ______________________________

Motor Type ______________________________

Identification Number ______________________________

Model Number ______________________________

Frame Type ______________________________

Number of Phases (AC) ______________________________

Horsepower ______________________________

Cycles (AC)__________

Speed (RPM)__________

Voltage Rating__________

Current Rating (Amperes)__________

Thermal Protection __________

Temperature Rating__________

Time Rating__________

Other Information __________

3. Determine the type of motor you are working with, such as ac induction, dc stepping, shaded-pole, etc. Consult with instructor if you cannot determine the specific type. What is the specific type?

4. In the following space, draw a schematic diagram of the motor. This will provide a general reference for later tests.

5. After the proper type of power source and voltage has been determined, apply power to the motor for a very brief period of time while attempting to detect the specific malfunction.
6. Describe the malfunctions which seem to exist in your motor.

7. If available, consult a symptom chart in a motor operation book or some other reference. List some possible causes of the malfunction.

8. Determine and list some possible corrections for the malfunction.

Name ______________________________

9. If the motor must be disassembled, remove the end plates carefully. Be particularly careful with the connecting wires and bearings. Remove the rotor assembly at this time. Check the bearings.
10. If connecting wires must be removed, use tape, or some other means to label the proper terminal connections.
11. Inspect all wiring connections, splices, and other mechanical connections for possible opens or shorts.
12. Inspect the stator portion of the motor for excessive dirt, oil, or other damage.
13. Check the rotor for visible damage.
14. If the rotor is the squirrel-cage type, it may be in need of cleaning with fine sandpaper.
15. If a wound rotor is used, check the commutator for high mica insulation, roughness, irregular wear, or other damage. You may wish to dress the commutator on a metal lathe, clean it with sandpaper, or remove high mica with an undercutting tool.
16. If the motor has brushes, check for excessive wear, oil, grease, chipping, or improper contact.
17. You may need to perform some resistance tests with the multifunction meter to determine the condition of the stator windings. (Example: Ac single-phase induction motor; start winding—20 ohms resistance; run winding—5 ohms resistance.) Of course, those resistances will vary. Record your resistance readings.

    Winding resistances = ______________________________

    ____

18. What can you conclude from the resistance test regarding the condition of your motor?

    ____

    ____

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    ____

19. You may test the rotor windings for damaged insulation with a megger. You may test the rotor for shorts, grounds, or open circuits with a growler.
20. Perform any other tests you feel may be needed to locate the trouble. Consult with your instructor.
21. Perform the necessary procedures to repair the motor.
22. Consult with your instructor when you feel you have completed the troubleshooting procedure and have repaired the motor malfunction.

    Instructor's Approval: ______________________________

23. This should complete your troubleshooting job. Return all materials to the storage area.

Analysis:

1. Write a detailed description of the troubleshooting process you have used in this experiment. Explain how you determined the trouble for this particular type of motor. Also, explain how you corrected the malfunction.

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Activity 19—Ac Synchronous Motors

Name ______________________ Date ______________ Score __________

Objectives:

The ac synchronous motor used in robotic systems is commonly classified as a constant-speed device. It has extremely rapid starting, stopping, and reversing characteristics. Motors of this type only necessitate a simple clockwise-stop-counter-clockwise rotary switch for control. The starting and running currents of a synchronous motor are identical, which is unique for ac motor. This characteristic means that a motor of this type can withstand a high inrush of current when direction changes occur. As a general rule, the synchronous motor can even be stalled without damaging the motor.

Motors of this type are commonly used as drive mechanisms for robotic systems in machinery operations. Starting begins within 1 1/2 cycles of the line frequency, and stopping occurs in five mechanical degrees of rotation. This motor represents a unique part of all servomechanisms used in precision rotary control applications today. In this activity, a simple test circuit will be constructed so that you may observe an ac synchronous motor's starting, stopping, and current flow characteristics.

Equipment and Materials:

- Ac synchronous motor—Superior Electric Type SS150 or equivalent motor rated at no more than 200 in/oz.
- Capacitor—3.75 µF, 330v ac.
- Resistor—250 Ω, 25 W.
- SPST switches (3).
- Isolated ac power source—120v.
- Ac ammeter—0-5 A.
- Piece of wood.

Safety:

Use protective eyewear during this activity.

Procedure:

1. Construct the ac synchronous motor test circuit of Figure 19-1. Ensure that the motor is mounted securely.

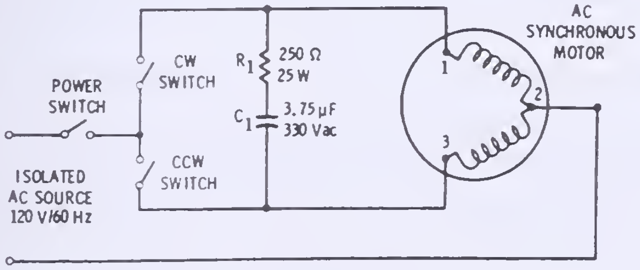

Figure 19-1. Ac synchronous motor test circuit.

2. Turn on the cw switch for clockwise rotation.
3. Momentarily turn on the power switch and observe the rotation of the motor.
4. With a tachometer measure the speed of rotation.

   Speed = __________ RPM.

5. Momentarily turn off the power switch and observe the stopping action of the synchronous motor. You may want to run several trials to see the quickness of the stopping action. How does this compare with other ac motors?

   ____

6. Note each time that the motor is turned on, how quickly it comes to speed.
7. With an ac ammeter, measure the running current and starting current of the synchronous motor.

   Running current = __________ amperes.

   Starting current = __________ amperes.

8. Carefully wedge a piece of wood between the rotating shaft and the bench while holding the motor. This will provide a simple loading method for test purposes.
9. When the motor is loaded down, how does the running current respond?

   ____

10. If the motor is completely stalled, how does the running current respond?

    ____

11. Remove the load from the motor, turn off the clockwise switch, and turn on the counter-clockwise switch. The motor should rotate equally well in the counter-clockwise direction and have the same basic characteristics. Test these again to verify the theory.
12. Switch off the counter-clockwise switch, then switch on the clockwise switch and notice the ease with which direction change occurs.
13. Turn off the ac power source and disconnect the circuit. Return all parts to the storage area.

Analysis:

1. Discuss the operation of an AC synchronous motor.

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Activity 20—DC Stepping Motors

Name ______________________________ Date ______________ Score ________

Objectives:

Dc stepping motors represent a unique electromechanical rotary actuator that is used in robotic systems. These motors are designed to change electrical pulses into rotary motion. The amount of rotary movement or angular displacement produced by each pulse is repeated precisely for each succeeding pulse. The resulting rotation of these motors may be used to accurately locate or position work tables or fixtures for automatic machining operations. Very precise degrees of accuracy can be achieved with these devices.

In this activity, you will construct a simple test circuit for a dc stepping motor. You will be able to produce very accurate shaft movements by different switching step combinations. Both the four-step and eight-step switching combinations will be tested. Through this activity, you will be able to observe the physical operation and test the accuracy of motor shaft rotation. The switching operation of this activity is achieved automatically by logic devices in actual operating circuits. Precise switching operations obviously improve the accuracy of this circuit.

Equipment and Materials:

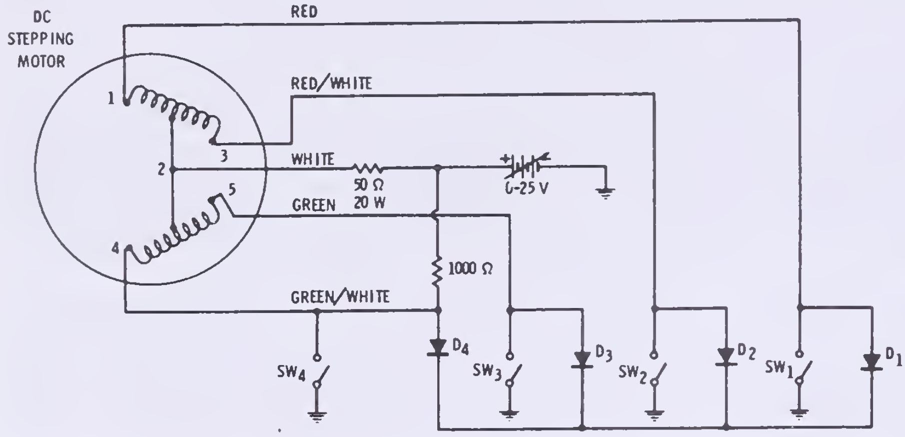
- Dc stepping motor—Superior Electric Type M061-FD02 or equivalent.
- SPST switches (4).
- Resistor—50 Ω, 20 W.
- Resistor—1000 Ω, 1/2 W.
- Dc power supply—0-25v, 1 A.
- Diodes—1N4004 (4).

Safety:

Use protective eyewear during this activity.

Procedure:

1. Construct the stepping motor test circuit of Figure 20-1.
2. The physical movement of the stepping motor shaft is small and rather difficult to observe. By attaching a simple indicating device such as a small wire or paper pointer to the motor shaft, the mechanical rotation can be readily observed.
3. The switching sequence in the full-step mode will produce 1.8° steps for each switching combination.
4. Adjust the dc power supply to 15 volts. Set the indicator to a starting position and mark it as the starting reference. Then turn on the switch combinations for Step 1 of the full-step mode from the chart of Figure 20-1.
5. Go to the next switching combination indicated by Step 2 of the chart. Each combination will produce a rotary step.
6. Follow the stepping procedure through at least two of the four-step cycles. Notice that the switching step combination repeats itself after Step 4.
7. Mark the indicator location as the stopping position for reference.
8. Calculate the rotational degrees by multiplying the number of steps by 1.8°.
9. If a protractor is available, measure the number of degrees of rotation between the starting indicator mark and the last switching location mark of the motor shaft.



FOUR-STEP INPUT (FULL-STEP MODE)

STEP	SW_1	SW_2	SW_3	SW_4
1	ON	OFF	ON	OFF
2	ON	OFF	OFF	ON
3	OFF	ON	OFF	ON
4	OFF	ON	ON	OFF
1	ON	OFF	ON	OFF

EIGHT-STEP INPUT (HALF-STEP MODE)

STEP	SW_1	SW_2	SW_3	SW_4
1	ON	OFF	ON	OFF
2	ON	OFF	OFF	OFF
3	ON	OFF	OFF	ON
4	OFF	OFF	OFF	ON
5	OFF	ON	OFF	ON
6	OFF	ON	OFF	OFF
7	OFF	ON	ON	OFF
8	OFF	OFF	ON	OFF
1	ON	OFF	ON	OFF

Figure 20-1 Dc stepping motor test circuit and stepping tables.

10. Repeat the procedure outlined in Steps 2 through 9 of this activity for the eight-step sequence. In this stepping mode, each step produces 0.9° of rotation.
11. Disconnect the circuit and return all components to the storage area.

Analysis:

1. Explain how a dc stepping motor operates?

2. How many steps are required by a dc stepping motor in the full-step mode to produce one revolution?

3. How many steps are required by a dc stepping motor in the half-step mode to produce one revolution?

4. Describe a typical application of the dc stepping motor.

Activity 21—Force through Liquids

Name ________________________________ Date ______________ Score __________

Objectives:

One of the most significant functions of a hydraulic power system is the transmission of force through a liquid. According to **Pascal's law,** pressure applied to a confined fluid is transmitted equally through the fluid in all directions, and is applied at right angles to the containing surfaces. Fluid does not have a specific shape, which allows it to conform to the internal features of the container. Fluid also has poor **compressibility**, which means it tends to resist compression when force is applied. These ideas are extremely important characteristics of an operating fluid power system.

In this activity, two hydraulic cylinders are interconnected to form a simple closed-loop fluid system. Through this system you will be able to observe how force is transmitted through a fluid. You will also have an opportunity to test the compressibility of a hydraulic fluid.

Equipment and Materials:

- Hydraulic fluid or other fluid.
- Double-acting cylinders—1 1/8″ bore (2).
- Assortment of quick-disconnect transparent tubing pieces.
- Safety glasses or goggles.

Safety:

Hydraulic power systems operate at high pressure. Always wear protective eyewear and check all fittings before starting any hydraulic system.

Procedure:

1. Attach a length of flexible tubing to the port opposite the piston end of one of the 1 1/8″ bore doubling-acting hydraulic cylinders. Position the unit horizontally, with the ram or piston retracted into the cylinder.
2. Place the unattached end of the flexible tubing into a cup of hydraulic fluid. Manually force the piston in and out of the cylinder several times to charge it with oil and clear it of air.
3. Pull the piston all of the way out, thus fully charging it with oil. Set it aside momentarily.
4. Attach a length of flexible tubing to the port nearest the piston end of the second 1 1/8″ bore, double-acting hydraulic cylinder.
5. Using the same procedure outlined in Steps 2 and 3, clear the cylinder of air and charge it with oil. The piston should ultimately be fully retracted when it is charged.
6. Connect the unattached ends of the flexible tubing to the other cylinder as indicated in Figure 21-1.
7. Have a lab partner hold cylinder 1 while you hold cylinder 2. Pushing the ram of cylinder 2 down will transfer the force of cylinder 2 through the fluid to cylinder 1.
8. If transparent flexible tubing is used you should be able to see the direction of fluid flow by watching any air bubbles trapped in the system.
9. Alter the position of the two cylinders and repeat the procedure. What does the results indicate about a hydraulic system?

   ____

   ____

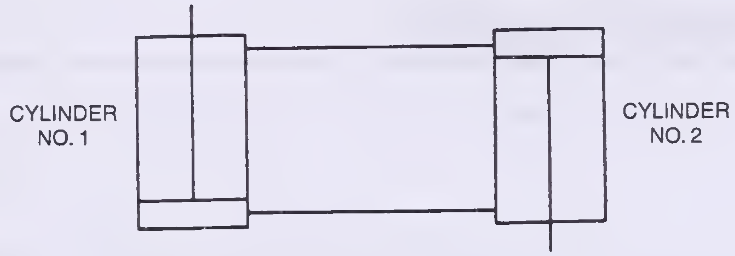


Figure 21-1 Hydraulic power test circuit.

10. Adjust the position of the two pistons so that they are near the center of the cylinders. Apply force to both pistons. Ideally there should be no compression of the fluid. Any trapped air in the system will permit some degree of compressibility. How does your system respond?

____

____

11. Momentarily remove the flexible tubing from cylinder 1. Force the cylinder down approximately 1/4″, then pull it back to its original position. Return the flexible tubing to the cylinder.
12. Adjust the position of the two cylinders near the center and repeat Step 10. How does the system respond?

____

____

13. Disconnect the flexible tubing from each cylinder and clear the cylinders of fluid. Wipe excess fluid off all components and return them to the storage area.

Analysis:

1. What is meant by the term *compressibility*?

____

____

2. Explain how force is transferred through a fluid.

____

____

3. Describe the mechanical action of a double-acting cylinder.

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____

Activity 22—A Static Hydraulic System

Name ____ Date ____________________ Score ____________

Objectives:

A hydraulic jack is one of the most common static fluid systems in operation today. With this system, a pump cylinder forces fluid into a ram cylinder through check valves. As a general rule, systems of this type are usually self-contained in a single housing.

In this activity, a simple hydraulic jack system will be constructed with discrete components. Through this activity you will have an opportunity to observe fluid flow through check valves that will permit an alternate direction of flow.

A hydraulic jack is often described as a static hydraulic system. This refers to the fact that the system develops its own operating pressure when energized by an outside mechanical force. A distinct mechanical advantage is developed by the two cylinders because of the differences in their size.

Equipment and Materials:

- Hydraulic fluid or other fluid.
- Single-acting cylinder—1 1/8″ bore.
- Single-acting cylinder—1/2″ bore.
- Check valves (2).
- Flow control valve (needle type).
- "T" connectors (2).
- Pressure gauge—160 lb/in^2.
- Assortment of quick-disconnect transparent tubing piece.
- Safety glasses or goggles.

Procedure:

1. Assemble the hydraulic circuit of Figure 22-1. The 1 1/8″ bore cylinder will serve as the ram of the hydraulic jack, and the 1/2″ bore cylinder as the pump. Mount both cylinders in an upright position.

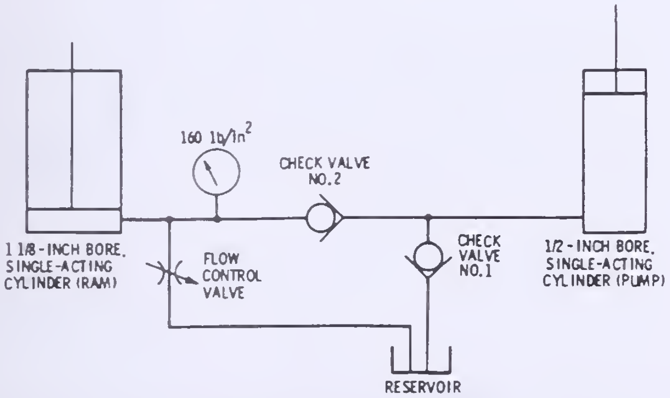

160 lb/in^2
CHECK VALVE NO.2
1 1/8-INCH BORE, SINGLE-ACTING CYLINDER (RAM)
FLOW CONTROL VALVE
CHECK VALVE NO.1
1/2-INCH BORE, SINGLE-ACTING CYLINDER (PUMP)
RESERVOIR

Figure 22-1 Hydraulic jack circuit.

2. Place the rams of both cylinders in the retracted position before attaching the flexible tubing to the cylinders, and close the flow control valve.
3. Pull the ram of the pump cylinder out of the cylinder, then for it down. One downward stroke of the pump cylinder causes the ram cylinder to move __________ centimeters.

4. How many strokes of the pump are needed to extend the ram?

   __________ strokes.

5. What pressure is indicated on the gauge?

   Pressure = __________ lb/in^2.

6. Open the flow control valve to drain the ram cylinder. Then close the valve to operate the system again.
7. Attach a weight of approximately ten pounds to the ram cylinder and repeat the operation of the jack.
8. What noticeable changes occur when the system is forced to do work?

   ____

   ____

9. Disconnect the system, drain the fluid from the cylinders and the tubing. Wipe any excess fluid from the components and return them to the storage area.

Analysis:

1. How much work was done by the ram cylinder in Step 7?

   ____

2. Describe the fluid circulation action that takes place during the operation of this system.

   ____

   ____

3. Does the pressure gauge change during the pumping action?

   ____

4. Why does this system have a mechanical advantage?

   ____

   ____

   ____

Activity 23—A Hydraulic Ram System

Name ______________________________ Date ________________ Score __________

Objectives:

Hydraulic presses or rams play a very important role in industry today. Mechanical systems of this type are actuated by an electric-motor-driven pump that serves as the source of hydraulic energy. The transmission path of the system distributes energy to the load device, which does some form of mechanical work. Flow and directional control are achieved by special valves in the transmission line. An indicator is used to display system pressure. The hydraulic fluid is sent back to the pump reservoir through a return line. Systems of this type are classified as active units when compared with the static systems of Activities 21 and 22.

In this activity, you will have an opportunity to identify some basic hydraulic components and their associated diagram symbols. You will then assemble these components into a functioning hydraulic ram system. You will be able to observe the change in the direction of fluid flow by valve action. The basic operating principle of this hydraulic system has widespread application in industrial machinery today.

Equipment and Materials:

- Hydraulic fluid or other fluid.
- Electric Hydraulic power unit.
- Flow control valve.
- Two-position, four-way, lever-action control valve.
- Doubling-acting cylinder—1 1/8″ bore.
- Pressure gauge—160 lb/in^2.
- “T” connector.
- Assortment of quick-disconnect transparent tubing pieces.
- Safety glasses or goggles.

Procedure:

1. Select the necessary components to construct the hydraulic ram circuit of Figure 23-1.

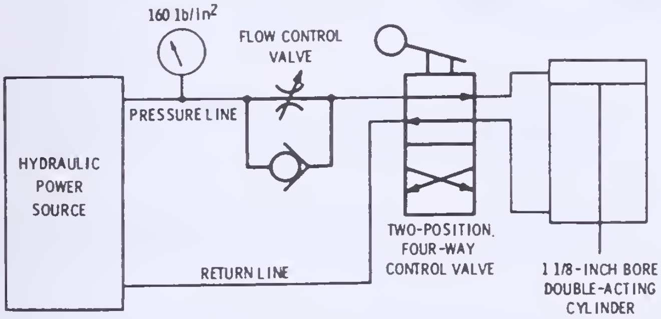

160 lb/in²
FLOW CONTROL VALVE
PRESSURE LINE
HYDRAULIC POWER SOURCE
RETURN LINE
TWO-POSITION, FOUR-WAY CONTROL VALVE
1 1/8-INCH BORE DOUBLE-ACTING CYLINDER

Figure 23-1 Hydraulic ram circuit.

2. Start the electric pump motor of the hydraulic power source. Slowly open the shutoff control valve of the circuit while observing the pressure gauge. Depending on the initial position of the four-way control valve, the ram of the cylinder may extend itself slowly. Record the system pressure.

   Pressure = __________ lb/in^2.

3. With the four-way control valve positioned as indicated in the circuit diagram, move the handle to the other position. What influence does this control action have on the ram of the double-acting cylinder?

4. Move the handle of the four-way control valve back to its original position to see the control action on the cylinder. Describe the action of the cylinder's ram.

5. The direction of fluid flow can be readily traced by the movement of air bubbles in the transparent tubing. Switch the control valve to extend the ram and observe the direction of fluid flow. If the bubbles are not present, they can be introduced by closing the flow control valve and momentarily disconnecting the return line from the four-way control valve. Depress the check valve in the line and let a small amount of hydraulic fluid drain from the line. Then return the line to the control valve and turn on the flow control valve.
6. Indicate the direction of fluid flow on the circuit diagram with solid line arrows.
7. Switch the control valve to a position that will cause the ram of the cylinder to retract. Trace the fluid flow through the circuit. Make a sketch of the flow direction with broken line arrows or with a different colored pen or pencil on the circuit diagram.
8. Turn off the electric pump motor of the hydraulic power source and disconnect the circuit. Wipe off any excess hydraulic fluid from the components and return them to the storage area.

Analysis:

1. What are the primary system functions of the circuit constructed in this activity?

2. What specific component of the circuit is used to achieve each system function?

3. How could the ram in this circuit be used in an industrial application?

4. How does this system differ from the static systems of Activities 21 and 22.

Activity 24—Hydraulic Power Source

Name ______________________________ Date ______________ Score __________

Objectives:

The power source of a hydraulic system is a fluid pump. This component is responsible for producing a fluid flow that will ultimately develop pressure when it is forced to pass through system components. A hydraulic pump must be in continuous operation whenever the system is operational. Through its action, hydraulic fluid is forced to move at a specific flow rate which causes a corresponding pressure to occur when resistance is encountered.

In this activity, you will study the basic components of a hydraulic power unit. This will include the hydraulic pump, reservoir, filters, relief valve, pressure manifold, and return manifold. Pressure developed by this power source is variable, with a maximum rating of approximately 300 lb/in^2. For most experimental applications, the power source needs values of 100 lb/in^2 or less. Typical industrial hydraulic power sources may, however, call for values in the 1000 to 3000 lb/in^2 range.

Equipment and Materials:

- Hydraulic fluid or other fluid.
- Hydraulic power source.
- Pressure gauge—160 lb/in^2.
- Assortment of quick-disconnect transparent tubing pieces.
- Measuring container—1/2 gal.
- Open-ended disconnect tubing piece.
- Safety glasses or goggles.

Procedure:

Section A. Power Source Analysis

1. A basic hydraulic power source is needed to perform this activity. As a general rule, most of the components of this unit are permanently mounted and ready for operation.
2. Locate the electric motor of the unit and plug it in to the appropriate electrical outlet. Trace out the electrical circuit and locate the motor/pump on/off switch. In many units, the pump and motor may be mounted in a single housing.
3. Locate the system reservoir. Trace the fluid flow path from the reservoir to the inlet side of the hydraulic pump. Does your unit employ a fluid filter in this line?

   ____

4. Trace the fluid path from the outlet side of the pump to the pressure manifold. Are there any filters or controls in this part of the system?

   ____

5. Where is the pressure relief valve of your system located?

   ____

6. Turn on the electric motor. Observe the pressure gauge and record the system pressure. If at all possible, see at what pressure the system returns fluid to the reservoir. This is determined by the pressure relief valve setting.
7. Connect a length of tubing to one of the pressure manifold valves. Run the other end of the tubing to an open tray or to the reservoir return line. Open the manifold valve momentarily until all of the air bubbles pass from the line. Does the pressure gauge change during this operation?

   ____

8. Turn off the electrical power to the pump drive motor. In the following space, make a sketch of your hydraulic power source pointing out specific component locations:

9. In the following space, draw a schematic diagram of the hydraulic power source using appropriate fluid power symbols:

Section B. Hydraulic Pump Delivery Rate

1. Attach a 160 lb/in^2 gauge to one of the pressure manifolds of the hydraulic power source. Connect a length of plastic tubing to the output side of a second manifold valve. Then connect the other end of the tubing to one of the return manifold connections.
2. Ready the hydraulic power source for operation by applying electricity and turning on the pump motor. Open the manifold valve attached to the pressure gauge. Record the system pressure. This valve also indicates the pressure setting or value of the pressure relief valve. If more than 100 lb/in^2 is indicated, ask the instructor to show you how to adjust the pressure limit.
3. Gradually open the manifold valve with the tubing attached. How does the system pressure gauge respond as this valve is opened?

---

4. Close the manifold valve and remove the plastic tubing with quick disconnects on each end. Replace it with a piece of tubing with a disconnect on only one end. The open end of the tubing will be used to fill a half-gallon measuring container to determine the pump delivery rate.
5. Open the manifold valve enough to maintain 100 lb/in^2 with the full output flowing through the tube. Fill the container and record the time it takes to pump 1/2 gallon. Run two trial tests at this pressure and average your results. Record your data in the chart in Figure 24-1.

Pressure (lb/in^2)	Half-Gallon Filling Time (seconds)	Pump Delivery Rate (GPM)	Calculated Horsepower*
100			
80			

$$\text{*Horsepower} = \frac{\text{gal/min} \times \text{lb/in}^2}{1714}$$

Figure 24-1 Hydraulic pump delivery data.

6. Repeat the procedure outlined in Step 5 for a pressure setting of 80 lb/in^2.
7. Calculate the horsepower delivered by the pump for each pressure setting, and record the data in the chart.

Name ______________________________

8. Turn off the power unit and disconnect all circuit components. Wipe them free of excess fluid and return them to the storage area.

Analysis:

1. Explain the operation of the hydraulic power unit investigated in this activity.

____

____

2. Explain how the system pressure is altered.

____

____

3. What is the function of the pressure relief valve?

____

____

4. What type of displacement does the pump of the hydraulic power unit supply?

____

Activity 25—Hydraulic Pumps

Name ______________________________ Date ______________ Score ________

Objectives:

A hydraulic pump is designed to provide an appropriate fluid flow that will ultimately develop system pressure. In an operating system, the pump accepts power from a drive motor and converts it into fluid flow.

Fluid flows into the inlet port of the pump and is expelled from the outlet port. After passing through the pump, fluid flow occurs at a faster rate. Ultimately, this increase in fluid flow causes an increase in system pressure when the flow encounters component resistance. Most hydraulic pumps displace a certain amount of fluid with each revolution of the impeller blade.

The gear pump in this activity is used to change rotary motion into fluid energy. Essentially this pump contains two gears enclosed in a precision machined housing. Rotary motion from the power source is applied to the drive gear. Rotation of this gear causes the second, or driven gear to turn, with their teeth meshing in the middle. The unmeshed gear teeth carry fluid from the inlet port to the center where the teeth mesh together and force the fluid to pass from the outlet port. Pumps of this type have an output capacity of from 0.5 to 1050 gallons per minute.

In this activity, you will construct a simple gear pump circuit and rotate the shaft of the pump manually to observe the direction of fluid flow. This will provide you with an opportunity to see how pump rotation and shaft speed influence the output of a hydraulic pump.

Equipment and Materials:

- Hydraulic fluid or other fluid.
- Bidirectional, fixed-displacement, gear motor/pump.
- Flow control valve.
- Double-acting cylinder—1 1/8″ bore.
- Assortment of transparent flexible tubing with disconnects.
- Safety glasses or goggles.

Procedure:

1. Connect the simple hydraulic pump circuit in Figure 25-1. The gear motor in this case will be used as a pump.

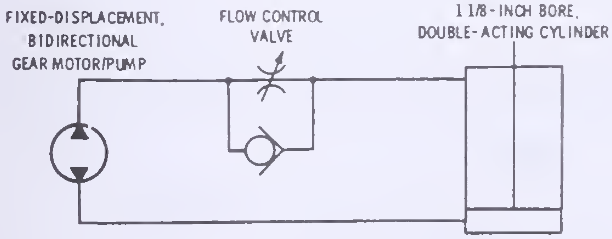

FIXED-DISPLACEMENT, BIDIRECTIONAL GEAR MOTOR/PUMP
FLOW CONTROL VALVE
1 1/8-INCH BORE, DOUBLE-ACTING CYLINDER

Figure 25-1 Hydraulic pump circuit.

2. Rotate the shaft of the pump in a clockwise direction with one hand while holding it with the other hand. The tubing pieces should contain enough fluid to make the system operational.
3. Continue to rotate the shaft until the ram of the double-acting cylinder begins to move.
4. Air trapped in the tubing pieces can be used to trace direction of fluid flow. Clockwise pump rotation causes the hydraulic fluid to flow in a __________ direction.
5. Rotate the shaft until the cylinder ram stops moving.

6. Rotate the shaft in a counterclockwise direction. Counterclockwise pump rotation causes hydraulic fluid to flow in a __________ direction.
7. Disconnect the circuit components and wipe off all excess fluid with a cloth. Return all components to the storage area.

Analysis:

1. How does pump speed of rotation influence the flow rate?

____

2. How does a gear pump produce fluid flow?

____

____

3. Explain the basic principle of fluid flow as achieved by a gear pump.

____

____

4. What would be a problem with a circuit of this type if it were connected to a drive motor?

____

____

Activity 26—Pressure Control Valves

Name ____________________ Date ____________ Score ________

Objectives:

When a hydraulic pump is in operation, it supplies fluid to the system with each revolution of the drive motor. With the hydraulic pump operating continuously, there is a need for an alternate flow path for fluid not used by the system. Pressure relief valves placed in the power source are designed to provide an alternate flow path when the need arises.

A pressure relief valve is a type of check valve that permits flow only when a certain pressure is reached. At reduced pressure, the valve checks the return flow and permits the fluid to pass into the system. At higher pressure levels it passes fluid back into the reservoir. In this application the relief valve is a safety device.

In this activity, you will have an opportunity to investigate the action of both a pressure relief valve and check valves more carefully. You will also have an opportunity to test the "cracking" pressure of the pressure relief valve. This refers to the release pressure that causes flow into the reservoir.

Equipment and Materials:

- Hydraulic fluid or other fluid.
- Hydraulic power source.
- Pressure relief valve.
- Flow meter.
- Flow control valve.
- Assortment of quick-disconnect hoses.
- Pressure gauge—160 lb/in^2.
- Safety glasses or goggles.

Safety Note:

You will be dealing with high system pressures in this activity. Follow all applicable safety procedures. *Do Not* allow system pressure to become excessively high.

Procedure:

1. Select the components needed to assemble the circuit of Figure 26-1. Notice the two paths for the fluid flow in this circuit. This represents a typical power source system divider.

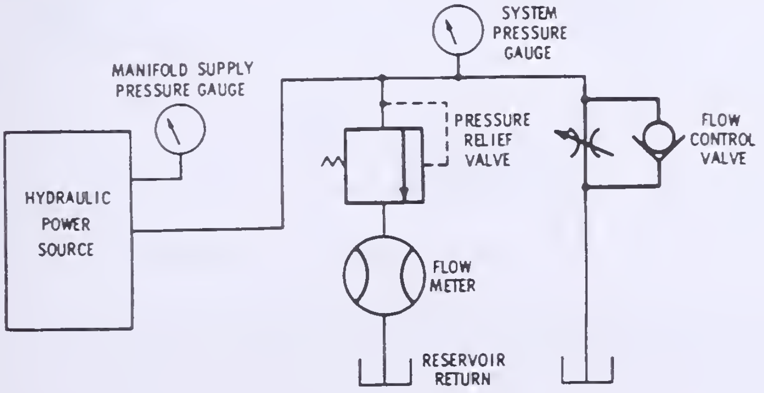


Figure 26-1 Hydraulic power source system divider circuit.

2. Adjust the pressure relief valve in the counterclockwise direction until it stops, then back off one turn of the valve control. Close the flow control valve completely.
3. Start the power unit and adjust the pressure relief valve to read 100 lb/in² of system pressure.
4. Open the flow control valve completely while observing system pressure. How does the pressure respond? Pressure with the flow control valve open is __________ lb/in².
5. Close the flow control valve again while observing the system pressure gauge. What does the flow meter do when the flow control valve is turned off?

   ____

6. Adjust the flow control valve to produce 100 lb/in² of system pressure. Then note the exact reading where flow first occurs through the flow meter. This is the **cracking pressure** of the valve.
7. Adjust the pressure relief valve one more turn as instructed in Step 2. Then adjust the flow control valve to 150 lb/in² of system pressure and determine the new cracking pressure of the pressure relief valve.
8. Turn off the power source and disconnect the circuit. Wipe all excess oil from the components and return them to the storage area.

Analysis:

1. What is the function of the pressure relief valve in a system of this type?

   ____

   ____

2. Define the term *cracking pressure*.

   ____

   ____

3. What is the function of a flow control valve in a hydraulic circuit?

   ____

   ____

4. What accounts for a difference in manifold supply pressure and system pressure?

   ____

   ____

   ____

   ____

Activity 27—Hydraulic Directional Control

Name ______________________ Date ______________ Score __________

Objectives:

Directional control of a hydraulic system is designed to alter the fluid flow in such a way that it can start, stop, or reverse the flow without altering system pressure appreciably. Valves that achieve this type of control are described as two-, three-, and four-way valves with different position settings. Controls of this type may be actuated manually by pressure, with electricity, or by mechanical energy.

In this activity, you will construct a simple hydraulic motor control circuit and test the direction of flow through the circuit with a flow meter. As a general rule, this type of flow indicator will only respond to flow in a single direction. You will also be able to test the direction of flow with respect to different circuit positions in order to see how this device alters the fluid flow. Through this experience, you will become more familiar with the basic components of a hydraulic system and be able to trace out the flow path from the manifold source to the reservoir.

Equipment and Materials:

- Hydraulic fluid or other fluid.
- Hydraulic power source.
- Pressure relief valve.
- Flow meter.
- Three-position, four-way control valve.
- Hydraulic gear motor.
- Assortment of quick-disconnect hoses.
- Safety glasses or goggles.

Procedure:

1. Select the components needed to construct the hydraulic circuit of Figure 27-1. Note the location of the four test points. In this activity, you will be asked to insert the flow meter into each test point and observe the direction of flow. The flow meter will only respond when the flow is from the inlet port to the outlet port. Flow in the reverse direction will not produce an indication on the meter.

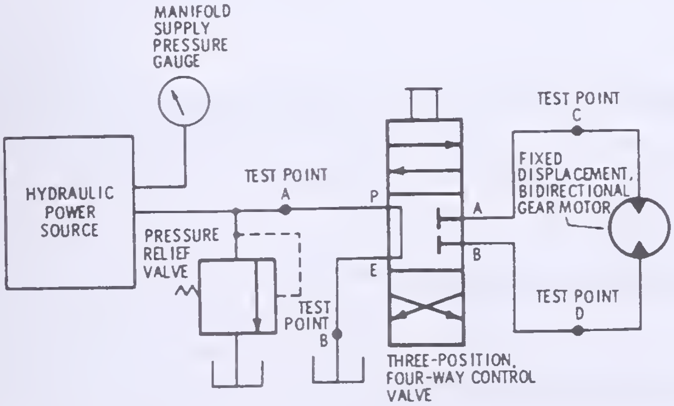

MANIFOLD SUPPLY PRESSURE GAUGE
HYDRAULIC POWER SOURCE
TEST POINT A
P
PRESSURE RELIEF VALVE
TEST POINT B
E
TEST POINT C
FIXED DISPLACEMENT, BIDIRECTIONAL GEAR MOTOR
A
B
TEST POINT D
THREE-POSITION, FOUR-WAY CONTROL VALVE

Figure 27-1 Hydraulic motor directional control circuit.

2. Close the pressure relief valve and back it off one complete turn. Then turn on the hydraulic power source and adjust the pressure relief valve for a manifold pressure of 100 lb/in^2 as indicated on the manifold supply gauge.
3. Momentarily turn off the power source and insert the flow meter into test point A. Then turn the power source on again.

4. Pull the position-shaft rod of the four-way valve to the fully extended position. Record the response of the flow meter and the motor.
5. Shift the control rod of the valve to the center position and record the flow meter and motor response.
6. Push the control rod into its most retracted position and note the flow meter and motor response.
7. Move the flow meter to test points B, C, and D, and repeat steps 4, 5, and 6. Record the direction of flow and motor response for each situation.
8. In the following space, draw three separate schematic diagrams with arrows showing the direction of fluid flow for each position of the four-way valve.

9. Turn off the hydraulic power source and disconnect the circuit. Wipe all components free of excess fluid and return them to the storage area.

Analysis:

1. What do the letter designations P and E on the four-way valve denote?

____

2. What are the three motor operating conditions of the four-way valve?

____

____

3. Would the four-way valve be classified as a full-control or partial-control device?

____

Activity 28—Hydraulic Linear Actuators

Name ____ Date __________________ Score __________

Objectives:

The fundamental purpose of a hydraulic power system is to produce some form of mechanical work. The part of the system responsible for achieving this function is called the load. The term *load,* however, is a rather broad term used to describe all components that consume power and do work. The term *actuator* is used more commonly to describe specific components in hydraulic systems that achieve the work function.

Linear actuators are designed to lift, hold, compress, or clamp objects during different manufacturing processes. Hydraulic cylinders are the most common linear actuator in operation today. These devices come in a variety of shapes and sizes that range from a fraction of an inch to several feet in diameter and length. The amount of force a cylinder can produce is determined by the surface area of the piston inside it and the pressure applied to it. Therefore, a cylinder with a larger surface area can produce more force than a smaller cylinder with the same pressure applied. Both single-acting and double-acting cylinders are included in the linear actuator classification.

In this activity, you will have an opportunity to construct a simple series and parallel linear actuator circuit and test the pressure and circuit operation under load and no load conditions. Through this experience you will become familiar with different system circuit configurations and observe some of the basic principles of series and parallel connected systems. Each type of circuit has a unique set of characteristics with respect to system pressure.

Equipment and Materials:

- Hydraulic fluid or other fluid.
- Hydraulic power source.
- Pressure relief valve.
- Three-position, four-way control valve.
- Pressure gauge—160 lb/in^2.
- Double-acting cylinder—1 1/8″ bore (2).
- "T" hose connectors (3).
- Assortment of quick-disconnect hoses.
- Safety glasses or goggles.

Procedure:

Section A. Series Linear Actuators

1. Select the appropriate components needed to construct the hydraulic circuit of Figure 28-1. Either a cylinder loading device or an actual weighted load needs to be attached to the cylinder in some steps of this activity.
2. Turn on the power source and adjust the pressure relief valve to 120 lb/in^2.
3. Push the control lever of the four-way valve into the valve while observing the pressure at test point A. Make this reading while the cylinders are moving.

   Test point A pressure = __________ lb/in^2.
4. Move the four-way valve to the center or "off" position and move the pressure gauge to test point B. Repeat Step 3 and record the pressure.

   Test point B pressure = __________ lb/in^2.
5. Return the four-way valve to the center or "off" position and move the pressure gauge to test point C. Repeat Step 3 and record the pressure.

   Test point C pressure = __________ lb/in^2.

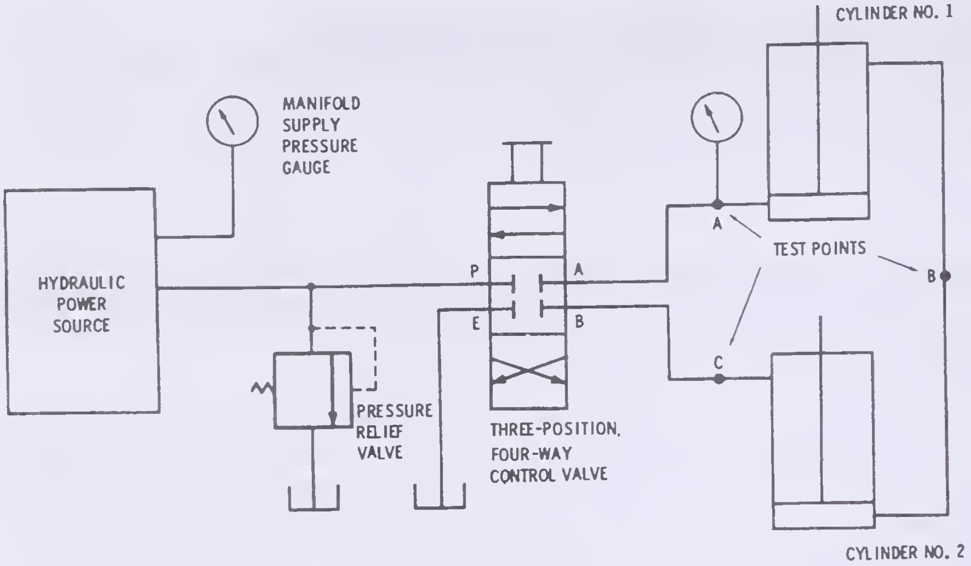


Figure 28-1 Hydraulic linear actuator circuit—actuators in series.

6. The pressure tests you just performed represent the no load test condition. If a cylinder loading device is available, connect it to cylinder 1 and adjust it to the heavy load condition. If a cylinder loading device is not available, attach a small platform plate to cylinder #1. Place 20 pounds of weight on the platform with the cylinder mounted in the vertical position.
7. Repeat Steps 3, 4, and 5 with the cylinder loaded. The pressure at test point C should be taken first since the gauge should be at this location from the previous test.
8. Make a chart showing the relationship of pressure between load and no load conditions at each test point.
9. Increase the system pressure to 160 lb/in^2 and test the operation of the circuit in its loaded condition. How does this added pressure alter cylinder operation?
10. Reduce the system pressure to 80 lb/in^2 and test the operation of the circuit in its loaded condition. How does it respond to reduced pressure?
11. Turn the power source off and disconnect the circuit.

Section B. Parallel Linear Actuators

1. Select the components needed to construct the hydraulic circuit of Figure 28-2.
2. Turn on the power source and adjust the pressure relief valve to 120 lb/in^2.
3. Push the control lever of the four-way valve into the valve while observing the pressure at test point A.

   Test point A pressure = __________ lb/in^2.

   Now pull the control lever completely out while observing the pressure. Make a pressure reading while the cylinders are in motion.

Name ______________________________________

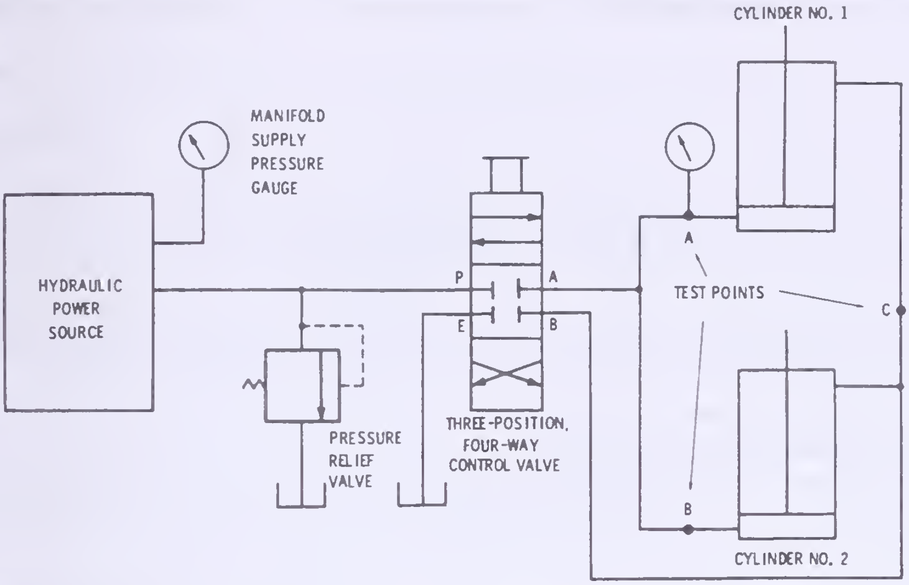


Figure 28-2 Hydraulic linear actuator circuit—actuators in parallel.

Pressure = __________ lb/in^2.

Does the flow direction influence the pressure?

____

4. Place the four-way control valve in the center or "off" position. Place the pressure gauge at test points B and C and repeat the procedure outlined step 3.

   Test point B pressure = __________ lb/in^2.

   Test point C pressure = __________ lb/in^2.

5. These tests represent the no load condition of the linear actuator. If a cylinder loading device is available, connect it to cylinder 1 and adjust it to the heavy load condition. If this device is not available, attach a small platform plate to cylinder 1. Place 20 pounds of weight on the platform with the cylinder mounted in the vertical position.
6. Repeat Steps 3, 4, and 5 with the cylinder loaded. The pressure at point C should be taken first since the gauge should be at this location from the previous test.
7. Make a chart showing the relationship between load and no-load pressure conditions at each test point.
8. Increase the system pressure to 160 lb/in^2 and test the operation of the circuit in its loaded condition. How does this added pressure alter the operation of the cylinders?

   ____

9. Reduce the system pressure to 70 lb/in^2 and test the operation of the circuit in its loaded condition. How does it respond to reduced pressure?

   ____

10. Turn off the power source and disconnect the circuit. Wipe all components free of excess fluid and return them to the storage area.

Analysis:

1. Why is this circuit described as a series linear actuator?
2. What influence does loading have on the pressure of a series linear actuator circuit?
3. What is a characteristic of the series circuit with respect to pressure throughout the system?
4. What general influence does system pressure have on the operational speed of a series linear actuator circuit?
5. Why is this circuit classified as a parallel linear actuator?
6. What influence does loading have on the system pressure of a parallel linear actuator system?
7. What is a characteristic of the parallel circuit with respect to pressure throughout the system?
8. What influence does system pressure have on the operational speed of a linear actuator?

Activity 29—Hydraulic Rotary Actuators

Name ______________________________ Date ______________ Score __________

Objectives:

Hydraulic rotary actuators are designed to produce an appropriate form of rotary motion in either direction. Fluid under pressure flows through the rotating member and causes it to move before it is expelled from the outlet side. Counterclockwise rotation is achieved by reversing the direction of fluid flow. These devices are used in industry today to open and close gates, for indexing operations, and in lifting operations. The speed of hydraulic rotary actuators is rather slow as compared to electric actuators, but they develop a great deal of torque.

In this activity, a hydraulic gear motor/pump device will be used as a rotary actuator. The turning ability of this device is a measure of the work the device is designed to do. Torque is used to describe the developed amount of work. It is determined by the developed force multiplied by the radius of the rotating arm. You will also have an opportunity to observe the influence of pressure and loading upon the rotational speed of the actuator. Rotary actuators represent a very important hydraulic system load device.

Equipment and Materials:

- Hydraulic fluid or other fluid.
- Hydraulic power source.
- Pressure relief valve.
- Three-position, four-way control valve.
- Flow meter.
- Pressure gauge—160 lb/in^2.
- Bidirectional, fixed-displacement, gear motor/pump.
- "T" connector.
- Assortment of quick-disconnect hoses.
- Tachometer.
- Safety glasses or goggles.

Procedure:

1. Select the appropriate components needed to construct the hydraulic circuit of Figure 29-1.

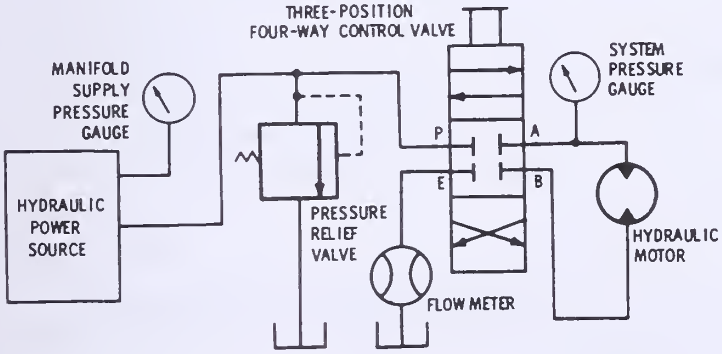


Figure 29-1 Hydraulic rotary actuator circuit.

2. Turn on the power source and adjust the pressure relief valve for 120 lb/in^2.
3. Push the control lever of the four-way valve into the valve while observing the direction of motor rotation.

   Direction of rotation is __________ (clockwise or counterclockwise).
4. Pull the valve control lever to its most extended position.

   Direction of rotation is __________.

5. Perform this test again and note the system pressure needed to produce rotation.
6. The flow meter indicates __________ GPM.
7. If a tachometer is available, measure and record the rotational speed of the motor. You can also measure speed when it is slow enough by marking the shaft and counting the number of revolutions per minute.

   Rotational speed = __________ RPM.
8. This represents the unloaded speed and pressure of the motor. Increase the pressure to 160 lb/in². Record the influence this has on speed and flow rate.

   Speed = __________ RPM.

   Flow rate = __________ GPM.
9. Reduce the pressure to 80 lb/in² and record the influence this has on speed and flow rate.

   Speed = __________ RPM.

   Flow rate = __________ GPM.
10. Attach a rotary load of some type to the mounted hydraulic motor.
11. Repeat Steps 2 through 10 with a substantial load on the motor. Record your findings in the chart in Figure 29-2.

Pressure (lb/in²)	Speed (RPM)	Flow Rate (GPM)
80		
120		
160		

Figure 29-2 Hydraulic rotary flow rate.

12. Turn off the power source and disconnect the circuit. Wipe all components free of excess hydraulic fluid and return them to the storage area.

Analysis:

1. What influence does system pressure have on motor speed and flow rate?

   ____

   ____
2. What influence does loading have on pressure and speed?

   ____

   ____
3. Explain how a hydraulic motor produces rotation.

   ____

   ____
4. What does the term *displacement* refer to in hydraulic motors?

   ____

   ____

Activity 30—Compressibility of Air

Name ______________________________ Date ______________ Score ________

Objectives:

The most significant difference in a hydraulic and a pneumatic power system is the compressibility of air with respect to fluid. Pneumatic systems, are designed to compress air into smaller volumes and increase its pressure. Compressed air can then be stored in a receiver tank and released when system demand for it arises. This removes the necessity of continuous pump operation that is characteristic of hydraulic systems.

The pressure associated with a pneumatic system can be expressed in a number of ways. Barometric, or absolute pressure, is 14.7 lb/in^2 at sea level. Gauge pressure is the difference in absolute pressure and an unknown system pressure. A gauge reading of 100 lb/in^2 represents an absolute pressure of 114.7 lb/in^2. Pressure below atmospheric pressure is commonly considered as a negative pressure or vacuum.

When a certain volume of air or gas is compressed, it causes a corresponding increase in pressure. Essentially, a decrease in container volume causes a corresponding increase in the density of the molecules. This, in turn, increases the rate at which the molecules strike the walls of the container, which causes a corresponding increase in pressure. Likewise, when the volume of a container is increased, it causes the gas molecules to spread apart. This in turn causes a corresponding reduction in total container pressure. This relationship is normally expressed by the ratio of: $P_1 \times V_1 = P_2 \times V_2$. P_1 and V_1 refer to the pressure and volume of the original container, while P_2 and V_2 refer to its reduced or expanded condition.

In this activity, you will have an opportunity to construct a simple pneumatic system and test the compressibility of air while observing the changes in pressure. The internal, or "blind-end," volume of a cylinder is based on the area of the piston times the length of the stroke. Cylinder area is measured in square inches or square centimeters and is determined by the formula

$$\text{Area} = D^2/4.$$

The blind-end volume of a cylinder is determined by the cylinder area multiplied by the stroke length, and is expressed in cubic inches or cubic centimeters.

Equipment and Materials:

- Air supply source—0-100 lb/in^2.
- Check valve.
- System pressure gauge—100 lb/in^2.
- Double-acting pneumatic cylinder—1 1/8″ bore.
- Assortment of quick-disconnect hoses.
- Safety glasses or goggles.

Safety Note:

Pneumatic systems, like hydraulic systems, operate at high pressure. Care should be exercised while working with pneumatic systems. Follow all safety procedures and use protective eyewear.

Procedure:

1. Construct the pneumatic circuit of Figure 30-1. Note that this circuit includes several items that are part of the primary air supply. These items are optional and may not be included in the air supply feeding each work area. The part of the circuit that you are primarily concerned with begins at the manifold supply valve.
2. Close manifold supply valves 1, 2, and 3 and open the manual shutoff valve of the air source. Adjust the system pressure regulator to read 15 lb/in^2 on the system pressure gauge.

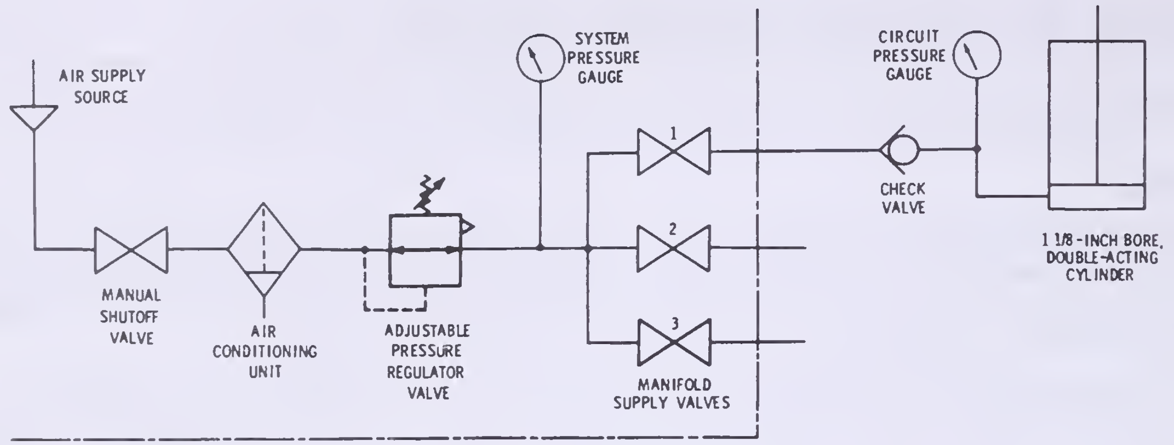


Figure 30-1 Pneumatic power test circuit.

3. Measure the length of the cylinder shaft when it is fully retracted.

   Length = __________ inches.

4. Slowly open manifold supply valve 1 while observing the action of the gauge and the cylinder. If the circuit does not respond, turn off the manifold valve and check the flow direction of the check valve.

5. When the cylinder ram is fully extended, measure and record the circuit pressure.

   Pressure = __________ lb/in^2.

   Measure and record the extended length of the cylinder ram.

   Extended length = __________.

   Calculate the blind-end volume of the cylinder.

   Cylinder volume = __________.

6. Manually force the piston back into the cylinder one-half of its extended distance while observing the circuit pressure gauge.

   pressure = __________ lb/in^2.

   Measure the extended rod length and calculate its blind-end volume.

7. Release the cylinder piston and let it extend again.

8. Adjust the supply regulator to 25 lb/in^2 and repeat Steps 3, 4, 5, and 6. How does this action differ from the preceding steps?

9. Close the manifold supply valve and the main air supply shutoff valve. Disconnect the circuit and return all components to the storage area.

Analysis:

1. Describe the relationship between blind-end cylinder volume and pressure.

2. What is the absolute pressure of Step 5?

Name ____

3. As pressure increases how does its compressibility change?

   ____

4. Why does pneumatic pressure increase when the volume of a container is reduced?

   ____

   ____

Activity 31—Pneumatic Source Analysis

Name ______________________________ Date ____________ Score ________

Objectives:

The air supply source is an extremely important part of a pneumatic system. It is usually energized by an electric motor that drives a compressor. The compressor, as the name implies, compresses air and forces it into the receiving tank. The receiving tank then holds the compressed air until needed by the system. Depending on the demand for air, the compressor's electric drive motor may only be called upon to operate when the air supply diminishes. The basic principle of air compression and storage represents a unique characteristic of a functional pneumatic system. Basic compressor types include reciprocating piston, centrifugal, and screw type.

In this activity, you will have an opportunity to study the supply system that feeds air to your work station. This part of the system typically includes a motor-driven compressor, a receiver tank, air conditioning equipment, pressure control valves, regulators, a distribution manifold, and pressure limit switches that respond to tank pressure changes. The air pressure capacity of the compressor is designed to meet the demands of the entire system. Typical industrial pneumatic systems operate within a range of 80 to 200 lb/in^2 gauge pressure.

Equipment and Materials:

- Operating air supply source.

Procedure:

1. With the assistance of the instructor, locate the primary source of the pneumatic system supplying your work station.
2. Describe the basic type of compressor employed by the system.

   ____

   ____

3. What are the essential parts of this specific air source?

   ____

   ____

4. Make a symbol diagram of the complete air source.
5. What is the maximum receiver tank pressure developed by the system?

   ____

6. At what pressure does the compressor motor turn on to build up receiver tank pressure?

   ____

7. Describe the distribution path from the receiver tank to your work station.

   ____

   ____

8. Describe some periodic maintenance procedures that must be performed on the compressor and air source components of this part of the system.

Analysis:

1. What are some of the primary differences in a hydraulic source and a pneumatic system source?
2. What are some of the basic compressor types in operation today?
3. How does compressing air increase its pressure?

Activity 32—Pneumatic Pressure and Flow

Name ______________________________ Date ______________ Score ________

Objectives:

When air passes through a pneumatic system, it normally encounters resistance that tends to reduce or lower the pressure between different locations. This lowering of pressure is primarily due to a form of friction that air encounters as it flows through the system. When air flow is reduced or stopped, it causes a change in friction. In a closed system without an air flow, the pressure is equalized throughout. When the flow of air increases, there is a corresponding increase in pressure drop. The length of the transmission flow path, the diameter of the tubing, number, and type of direction changes, and path restrictions all have some influence on the amount of pressure drop developed within a system.

In this activity, you will have an opportunity to construct a simple pneumatic system and alter the flow of air to see how it influences system pressure. You will be able to observe both an equalized system condition and the pressure drop of a heavy flow circuit. These conditions are very important considerations in the operation of a pneumatic system.

Equipment and Materials:

- Air supply source.
- Flow control valve.
- Pressure gauge—0-100 lb/in^2.
- Manual shutoff valve.
- Muffler.
- "T" connector.
- Assortment of quick-disconnect hoses.
- Safety glasses or goggles.

Procedure:

1. Construct the pneumatic circuit of Figure 32-1.

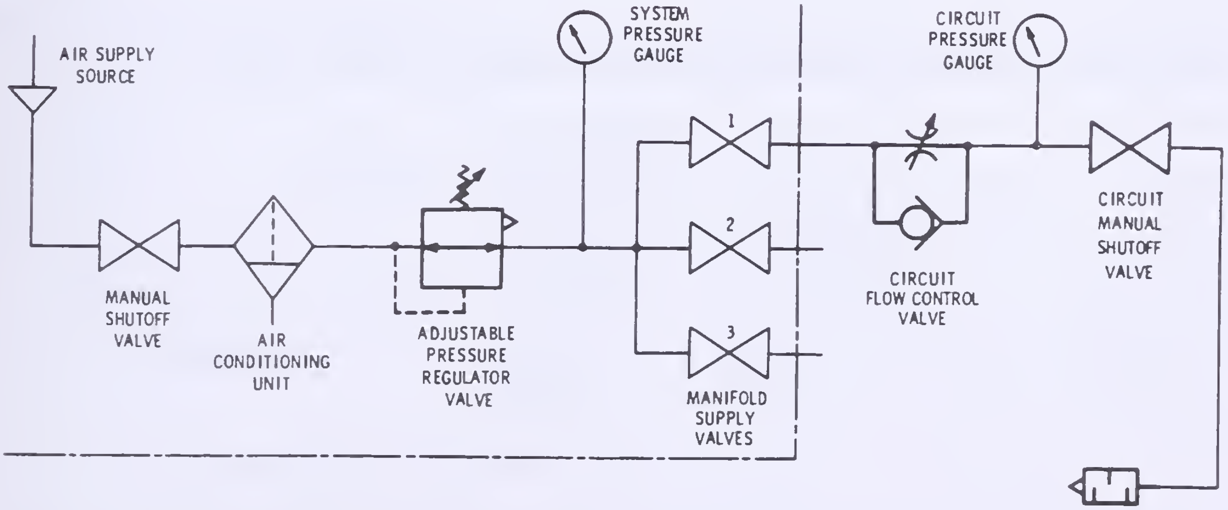


Figure 32-1 Pneumatic pressure and flow test circuit.

2. Close the manifold supply valves and turn on the manual shutoff valve. Adjust the pressure regulator valve to 15 lb/in^2 of system pressure. Close the circuit flow control valve and the circuit shutoff valve, then slowly open

the manifold supply valve. The circuit pressure gauge should read zero at this time if everything is adjusted properly. If not, check the two circuit valves and make certain they are off.

3. Gradually open the flow control valve to produce a reading on the circuit pressure gauge. How does this reading compare with the system pressure?
4. Open the circuit manual shutoff valve. How do the two gauge pressures compare?
5. Turn off the circuit shutoff valve and add approximately six feet of hose between the muffler and the shutoff valve.
6. Turn on the manual shutoff valve again and observe circuit pressure. What influence does the additional hose have on the pressure reading?
7. Turn off the circuit shutoff valve and remove the muffler with the six-foot length of hose remaining.
8. Turn on the shutoff valve and observe the pressure reading. How does this compare with the value of Step 6?
9. Turn off the manifold supply valve and the manual shutoff valve of the air supply. Disconnect the circuit and return all components to the storage area.

Analysis:

1. What causes the pressure of a pneumatic circuit to drop at different locations?
2. What is meant by the term *system resistance?*
3. What are some of the things that alter the resistance to the flow of a pneumatic system?

Activity 33—Pneumatic Linear Actuators

Name ______________________ Date ______________ Score ________

Objectives:

Pneumatic linear actuators are primarily used in industrial applications to lift, compress, hold, or position objects during different manufacturing processes. In order for this action to be achieved, air is fed into a chamber under pressure. A piston or ram in the chamber is then forced to move depending on the applied pressure. Pneumatic cylinders range in size from a fraction of an inch to several inches in diameter. Both single-acting and double-acting cylinders are used to achieve linear mechanical action in pneumatic circuits.

In this activity, you will have an opportunity to construct a simple linear actuator circuit to test the lifting capabilities of air. You will have an opportunity to observe this condition of operation with no load and under a loaded condition. Through this experience, you will become more familiar with basic pneumatic circuits and their operation. You will also have an opportunity to employ a flow control valve, which serves as a throttle that alters cylinder operating speed. This circuit modification is very important in many industrial applications today.

Equipment and Materials:

- Air supply source.
- Three-position, four-way control valve.
- Single-acting cylinder—1 1/8″ bore.
- Double-acting cylinder—1 1/8″ bore.
- “T” connectors (2).
- Pressure gauges—0-100 lb/in^2 (2).
- Flow control valve.
- Assortment of quick-disconnect hoses.
- Platform plate and 10-pound weight.
- Safety glasses or goggles.

Procedure:

Section A. Single-Acting Linear Actuators

1. Construct the linear actuator circuit of Figure 33-1. Note that the four-way valve has a plug attached to part of the valve that is not used.

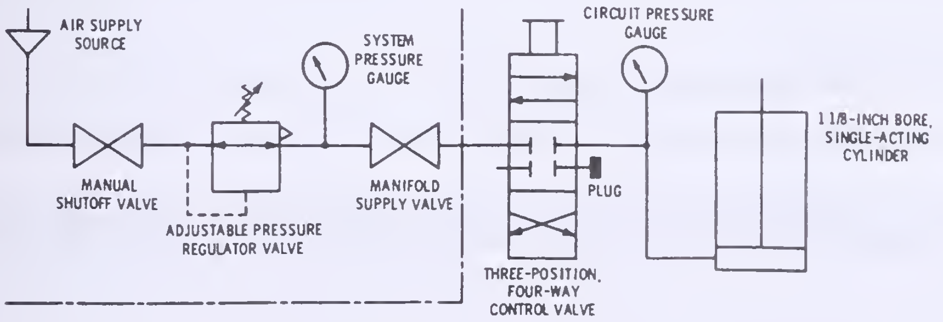

AIR SUPPLY SOURCE
SYSTEM PRESSURE GAUGE
CIRCUIT PRESSURE GAUGE
1 1/8-INCH BORE, SINGLE-ACTING CYLINDER
MANUAL SHUTOFF VALVE
ADJUSTABLE PRESSURE REGULATOR VALVE
MANIFOLD SUPPLY VALVE
PLUG
THREE-POSITION, FOUR-WAY CONTROL VALVE

Figure 33-1 Single-acting pneumatic linear actuator circuit.

2. Turn off the manifold supply valve. Energize the air supply source and adjust the pressure regulator valve for 15 lb/in^2.

3. Turn on the manifold supply valve and switch the four-way valve to all three positions. Describe the action of the cylinder.

4. Place a weight on the cylinder or load it by holding it down with your hands. Run through the switching sequence again with an increased load. How does this influence the action of the cylinder?

5. Increase the system pressure to 40 lb/in² and repeat Steps 3 and 4. How does increased pressure alter the operation of the cylinder?

6. Turn off the manifold supply valve and insert the flow control valve as indicated in Figure 33-2.

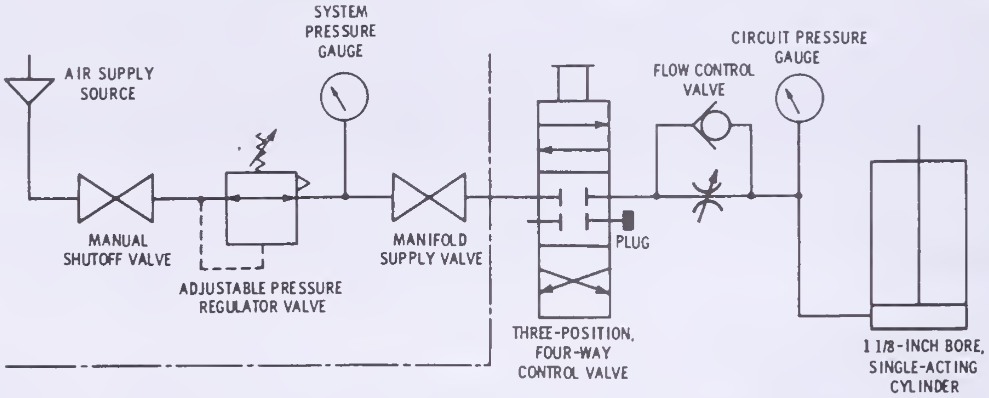


Figure 33-2 Circuit from Figure 33-1 with flow control valve added.

7. Turn on the manifold supply valve and switch the four-way valve to all three positions. In the retracting position, the flow control valve should be altered to regulate and retracting speed. This type of valve serves as a throttle to regulate cylinder retraction.
8. Turn off the manifold supply valve and reverse the flow direction of the flow control valve.
9. Turn on the manifold supply valve and switch the four-way valve through its three positions. How does this alteration change the operation of the circuit?

10. Turn off the manifold supply valve and the air supply shutoff valve. Disconnect the circuit and return all parts to the storage area.

Section B. Double-Acting Linear Actuators

1. Construct the double-acting linear actuator circuit of Figure 33-3.
2. Turn off the manifold supply valve of the air supply and energize the source. Adjust the regulator pressure to 40 lb/in².
3. Turn on the manifold supply valve and switch the four-way valve to all three positions. Make a note showing the extended and retracted positions of the four-way valve. How do the pressure readings respond during operation of the cylinder?

4. Attach a platform to the top of the cylinder with the cylinder extending upward. Place a 10-pound weight on the platform and repeat Step 3. What influence does an increased load have on the operation of the circuit?

Name ______________________________

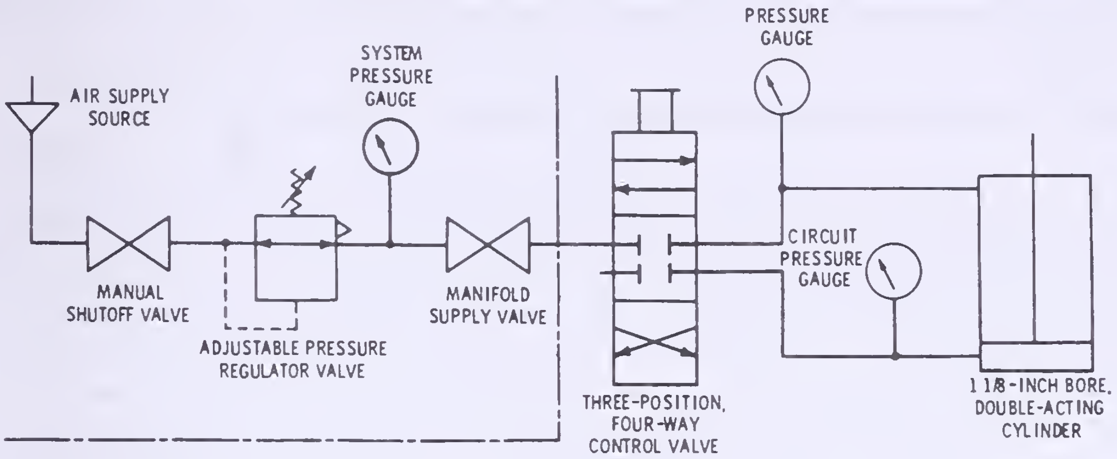


Figure 33-3 Double-acting pneumatic linear actuator circuit.

5. Turn off the manifold supply valve and place a flow control valve in the top cylinder line of the circuit. Connect as in Figure 33-2 so that the free flow is from the four-way valve to the cylinder with the throttled flow and from the cylinder to the four-way valve.
6. Turn on the manifold supply valve and switch the four-way valve to all three positions. In the retracting position, the flow control valve should be adjusted to produce a slow retracting action.
7. Turn off the manifold supply valve and switch the location of the flow control valve to the bottom line.
8. Turn on the manifold supply valve and switch the four-way valve through its three positions. How does the control valve alter the operation of the cylinder in this circuit location?

   ____

9. If two flow control valves are available, you can place one in each cylinder line and alter the operational speed of the valve in both the retracting and extending positions.
10. Turn off the manifold supply valve and the air supply shutoff valve. Disconnect the circuit and return all parts to the storage area.

Analysis:

1. What is an industrial application of a pneumatic circuit of the type studied in this activity?

   ____

   ____

2. What is a unique difference in this circuit operation and that of a similar hydraulic circuit?

   ____

   ____

3. Explain the operation of the throttling valve technique of cylinder speed control.

   ____

   ____

4. Make a circuit diagram for each of the three operating positions of the four-way valve with arrows showing the path of the air flow.

5. Why is the doubling-acting linear actuator considered to have better control than a single-acting cylinder?

____

____

6. Why does the four-way valve not require modification in this circuit as it did in Figure 33-1.

____

____

Activity 34—Pneumatic Rotary Actuators

Name ______________________________ Date ______________ Score __________

Objectives:

Pneumatic rotary actuators are designed to produce rotary motion from air pressure. Air under pressure is applied to the rotating member, causing it to move. The air is then expelled from the outlet side. Reversing the direction of air flow causes the motor to rotate in the opposite direction. Pneumatic motors are lightweight, compact, and have a wide range of variable speed characteristics when compared with electric or hydraulic motors. These characteristics are well suited for hand power tools, hoists, mixers, and in explosion-proof applications.

The horsepower and speed of a pneumatic motor can readily be changed by throttling the applied air flow. As the load applied to a pneumatic motor is increased, it normally causes a reduction in operational speed. This behavior is similar to that of an electric motor. With an increased load to an electric motor, however, the speed of rotation must quickly return to the normal running speed or it will be damaged by excessive heat. Excessive loading of a pneumatic motor will not adversely damage the motor because the air flow has a significant cooling effect. It can be run at alternate speeds without adverse damage to the motor for prolonged periods of time.

Pneumatic motors are energized by air, which means that they can be used in potentially explosive environments. This characteristic is extremely important in many industrial applications today.

The motor used in this activity produces up to 1/3 horsepower and operates from 500 to 10,000 RPM. It is primarily designed to respond to pressures below 100 lb/in^2. The amount of air flow needed to operate this motor is quite high, however. As a rule, the overall operating efficiency of a pneumatic motor is less than 20% for continuous operation. Air motors are rarely used when operational efficiency is important. They are used where the variable speed characteristic or explosion-proof advantage outweighs efficiency.

In this activity, you will construct a simple pneumatic motor circuit and test the loading effect on applied pressure and speed. You will then test the direction of rotation and see if loading and speed are altered. Through this activity, you will become more familiar with the operation of a pneumatic motor and see how rotary actuators can be harnessed to do work.

Equipment and Materials:

- Air supply source.
- Flow control valve.
- Three-position, four-way control valve.
- Reversible pneumatic motor—Gast No. 1AM vane type or equivalent.
- Muffler.
- Assortment of quick-disconnect hoses.
- Pressure gauges—0-100 lb/in^2 (2).
- Safety glasses or goggles.

Procedure:

Section A. Rotary Actuator Characteristics

1. Construct the rotary actuator circuit of Figure 34-1.
2. Turn off the manifold supply valve, then energize the air supply. Adjust the pressure regulator valve for 30 lb/in^2 of system pressure.
3. Close the flow control valve, then open the manifold supply valve. Slowly open the flow control valve while observing the circuit pressure gauge. At what pressure does rotation occur?

   Rotation occurs at __________ lb/in^2.

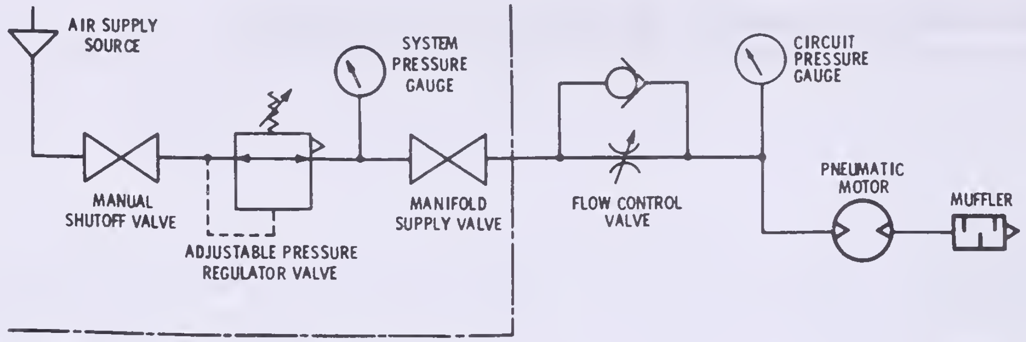


Figure 34-1 Pneumatic rotary actuator circuit.

4. Note the direction of motor rotation.

   Direction of rotation is __________ (clockwise or counterclockwise).

5. Gradually increase the flow while observing the circuit pressure. What is the maximum pressure observed?

   Maximum pressure = __________ lb/in^2.

   Note that when the pressure increases, the speed increases accordingly.

6. Connect a tachometer to the motor shaft and test the no-load speed.

   Speed = __________ RPM.

7. Load the motor by carefully wedging a piece of wood between the rotating shaft and the base of the motor. How does loading influence speed and circuit pressure?

   ____

8. Momentarily turn off the manifold supply valve and wait for the motor to stop rotation.

9. Adjust the pressure regulator valve to 70 lb/in^2 of system pressure. Close the flow control valve.

10. Turn on the manifold supply valve and gradually turn on the flow control valve. The motor should be loaded with the wooden wedge again. Increase the flow until rotation occurs. What circuit pressure is needed to produce initial rotation of the motor under a loaded condition?

    Pressure = __________ lb/in^2.

    How does this compare with the unloaded condition of Step 3?

11. Turn off the manifold supply valve and turn off the air supply source. Disconnect the circuit and return all components to the storage area.

Section B. Rotary Actuator Directional Control

1. Construct the rotary actuator circuit of Figure 34-2.

2. Turn off the manifold supply valve and energize the air supply source. Adjust the pressure regulator valve to 70 lb/in^2 of system pressure.

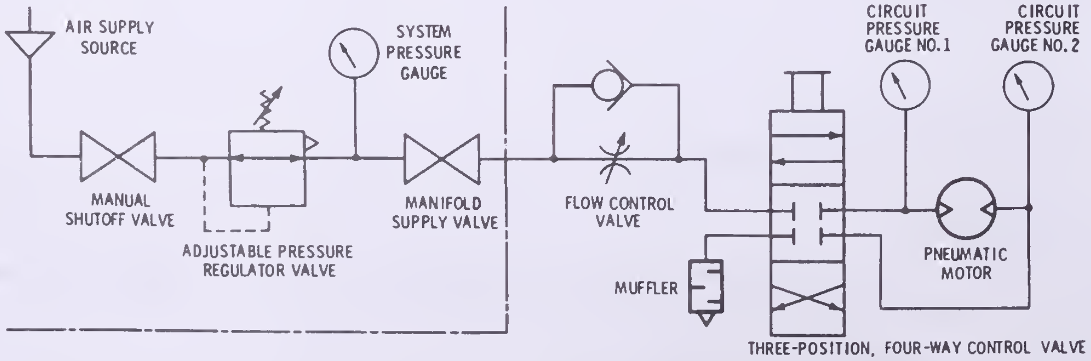

AIR SUPPLY SOURCE
SYSTEM PRESSURE GAUGE
CIRCUIT PRESSURE GAUGE NO. 1
CIRCUIT PRESSURE GAUGE NO. 2
MANUAL SHUTOFF VALVE
MANIFOLD SUPPLY VALVE
FLOW CONTROL VALVE
ADJUSTABLE PRESSURE REGULATOR VALVE
PNEUMATIC MOTOR
MUFFLER
THREE-POSITION, FOUR-WAY CONTROL VALVE

Figure 34-2 Pneumatic rotary actuator directional control circuit.

Name ______________________________

3. Turn off the flow control valve, then turn on the manifold supply valve. Switch the four-way directional control valve to each of the three positions. Then switch the four-way valve to one of its extreme positions.
4. Carefully adjust the flow control valve to produce a slow rotation of the motor. Make a note indicating the direction of rotation produced by this switch position.
5. Record the pressure indicated by gauges 1 and 2.

   Gauge No. 1 = __________ lb/in^2.

   Gauge No. 2 = __________ lb/in^2.
6. Switch the four-way control valve to the center or "off" position. Wait momentarily until rotation stops. Then switch the four-way control valve to the other extreme position. Make a note indicating the direction of rotation produced by this switch position.
7. Record the pressure indicated by gauges 1 and 2.

   Gauge No. 1 = __________ lb/in^2.

   Gauge No. 2 = __________ lb/in^2.
8. Increase the speed of rotation by opening the flow control valve. With a tachometer, measure the rotational speed. (Note: Some tachometers will only indicate speed in one rotational direction. Test the tachometer before making this measurement.)

   Speed = __________ RPM.
9. Switch the four-way control valve to the "off" position until the motor stops. Then switch it to produce rotation in the opposite direction. Observe the note in Step 8.

   Speed = __________ RPM.

   Does the motor run equally well in either direction?

   ____
10. If time permits, repeat Steps 1-9 after wedging a piece of wood between the motor shaft and its base as a loading device.
11. Turn off the manifold supply valve and the supply shutoff valve. Disconnect the circuit and return all parts to the storage area.

Analysis:

1. What influence does loading have on motor starting torque and the applied starting pressure?

   ____

   ____
2. How does loading alter the rotational speed of a pneumatic motor?

   ____

   ____
3. Of what significant advantage would a pneumatic motor have in industry?

   ____

   ____
4. How would the pressure gauges of this circuit respond if the muffler were removed?

   ____

5. What are some of the common types of pneumatic motors in operation today?

6. What kind of pneumatic motor is used in this activity?

7. How does a pneumatic motor compare with an electric motor?

Activity 35—Industrial Symbols and Diagrams

Name ______________________________ Date ______________ Score __________

Objectives:

In Activity 12, basic electrical symbols were reviewed. There are several symbols that are unique to industrial applications. In this activity, you will examine some common industrial symbols and diagrams shown in Figure 35-1.

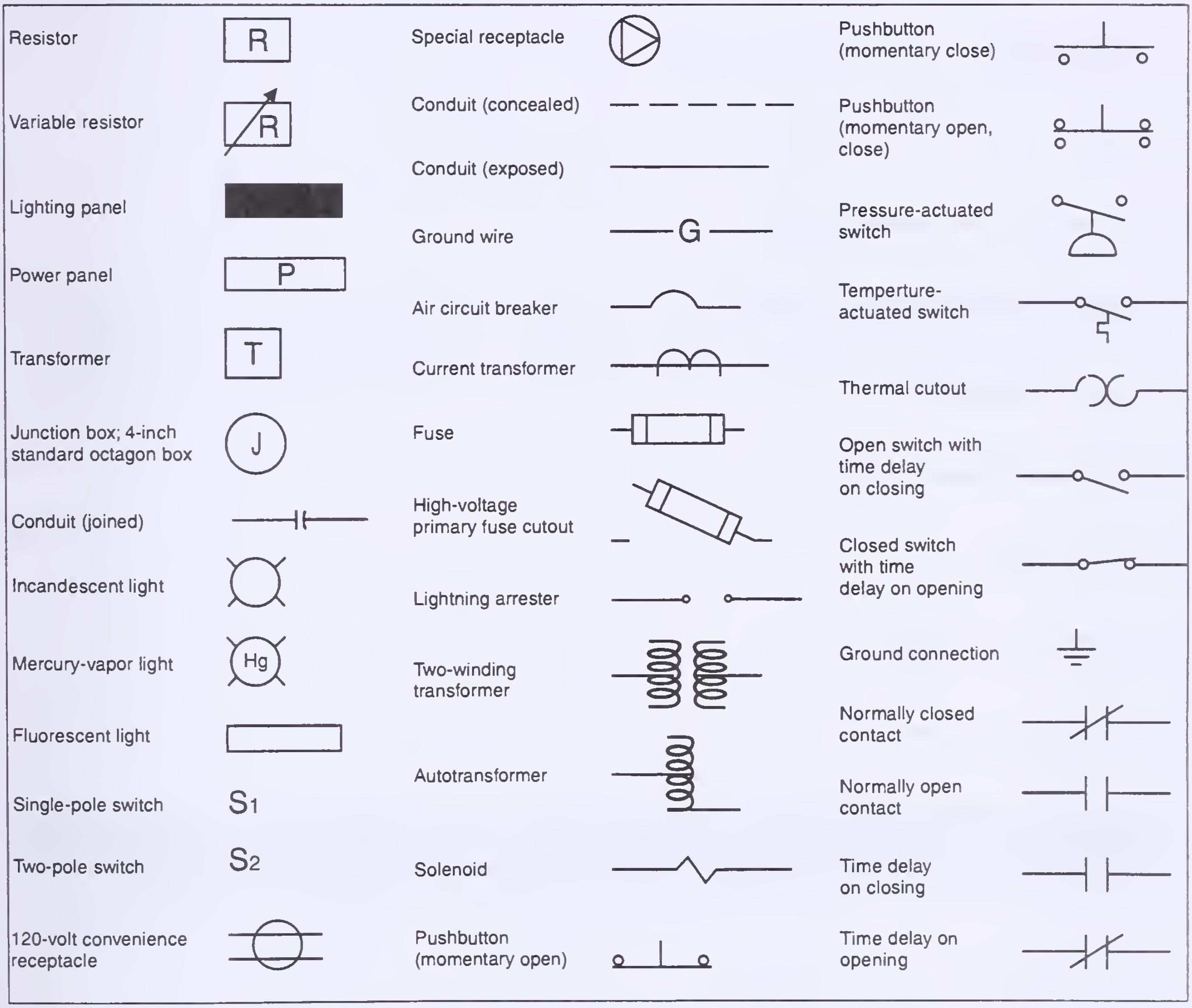


Figure 35-1 Industrial schematic symbols.

Industrial Diagrams:

The most common diagrams used to illustrate the components, circuits, and subsystems of an industrial system are connection diagrams, block diagrams, schematic diagrams, and one-line diagrams.

In this activity, you will need to do some research to locate some simple industrial systems that may be represented by using the appropriate type of diagram.

Analysis:

In the space next to each listed device, draw the proper symbols for that device.

1. Incandescent lamp

2. Mercury vapor lamp

3. Fluorescent lamp

4. Circuit breaker

5. Fuse

6. Pushbutton switch (normally open)

7. Pushbutton switch (normally closed)

8. Pressure-actuated switch

9. Temperature-actuated switch

10. Thermal cutout

11. Normally closed contact

12. Normally open contact

13. *Connection Diagram:* The connection diagram shows the physical relationships of the parts of a system. It is used to identify various parts for installation or servicing. The wires that interconnect circuits are ordinarily shown in their correct location. In the following space, draw a simple connection diagram for an industrial system:

Name ______________________________

14. *Block Diagram:* The block diagram is a very general method used to show low subsystems of any industrial system fit together to form a functional unit. Rectangles are used to represent subsystems and arrows are used to connect the blocks and show the interrelationships of subsystems. In the following space, draw a block diagram of an industrial system:

15. *Schematic Diagram:* The schematic diagram is used to show the electrical circuit relationships of the various components of an operational system. The electrical, but not necessarily the physical layout of the circuit is shown. This type of industrial diagram is the most often used. In the laboratory activities that follow, this type of diagram will be used. In the following space, draw a schematic diagram of an industrial circuit:

16. *One-Line Diagram:* The one-line diagram is a simplified form of the schematic diagram. This type of diagram is used to show how the components of a system fit together. It is similar to the block diagram in several respects; however, actual symbols, rather than rectangular shapes are used to show component parts. In the following space, draw a one-line diagram of an industrial system:

Activity 36—Reed Switches

Name ______________________ Date ______________ Score ________

Objectives:

Reed switches are devices that respond to a controlled magnetic field. They are designed to close or open when exposed to either a permanent magnetic field or to an electromagnetic field.

The contacts of a reed switch are housed inside a hermetically sealed glass tube. When actuated, contact sparks are isolated from the outside environment. Industrial applications of this device are quite numerous in explosive areas and dirt-prone environments. They are used to verify Z axis movement on some robots.

A reed switch contains two flat metal strips, or "reeds," housed in a hollow glass tube filled with an inert gas. When the reeds are exposed to a magnetic field, they are forced together, making or breaking contact depending on their design. The normally closed switch breaks contact when exposed to a magnetic field. Normally open contacts, by comparison, are forced closed when exposed to a magnetic field.

In this activity, you will construct a simple electrical circuit and control its action by changes in magnetic field strength. Through this experience you will gain some insight into the operation, sensitivity, and control action of a reed switch.

Equipment and Materials:

- Dc power supply—0-5v, 1.0 A.
- Ac power source—6.3v, 60 Hz.
- Reed switch—GE-X7 or equivalent.
- Bobbin-wound, reed switch coil.
- Reed switch magnet.
- Lamp—No. 47.
- Switch—SPST.
- Circuit construction board.

Procedure:

1. Construct the reed-switch circuit of Figure 36-1.

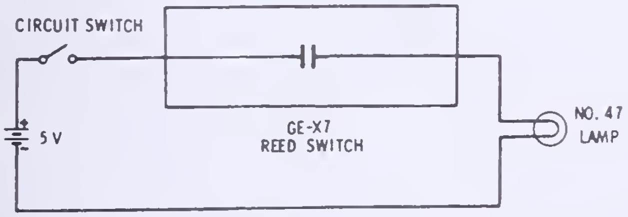


Figure 36-1 Reed switch test circuit for observing permanent magnet actuation.

2. Turn on the circuit switch and move the small permanent magnet near the reed switch. Try the magnet at a right angle with reeds, parallel with the reeds, etc. Which type of magnet orientation produces the best control capability?

   ____

3. Place the reed switch in the center of the bobbin-wound coil. Connect the circuit of Figure 36-2 to test the electromagnetic action of the reed switch.
4. Turn on the ac power source and the dc coil-control circuit.
5. Starting at zero volts dc, gradually increase the dc source voltage until the reed switch is actuated. The meter

should be set at a high range until an approximate actuating value is determined. Run at least two trial tests to determine the actuating current needed to energize the switch.

Dc actuating current = __________ milliamperes.

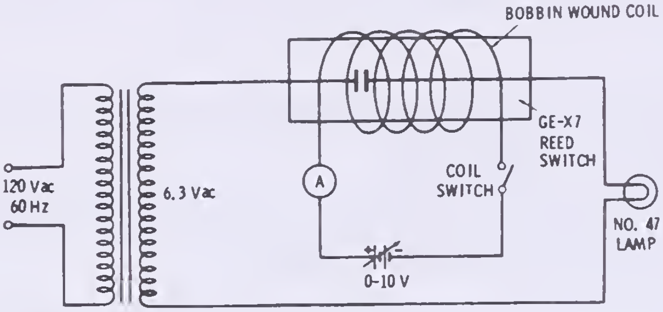


Figure 36-2 Reed switch test circuit for observing electromagnetic actuation.

6. In some applications, the actuating coil is used to increase the sensitivity of the reed switch by producing a partial field. Increase the dc coil current close to the actuating value. Then place the permanent magnet near the coil to actuate the reed. In this case, the switch can have some degree of variable sensitivity.
7. Turn off the ac and dc power sources for the circuit of Figure 36-2. Use 5v dc to supply the coil. The primary side of the coil should be connected to a variable ac transformer.
8. Turn on both the ac and dc sources, then increase the ac voltage applied to the coil. Measure the applied ac voltage. Do not increase the voltage to a value that will cause the reed coil to overheat. How does the reed switch respond to ac compared with dc?
9. Turn off the ac and dc power sources and disconnect the circuit. Return all components to the storage area.

Analysis:

1. How could a reed switch be used to control a pump motor in a liquid sump tank?
2. Make a sketch of this circuit.
3. How could a reed switch be used to control a circuit in an explosive area without danger of an explosion?

Activity 37—Liquid Level Control

Name ______________________________ Date ______________ Score __________

Objectives:

Many industrial processes rely upon liquid level measurement. Sometimes variables such as fuel supply are monitored continuously. There are several techniques which may be used to measure liquid level.

The measurement of liquid level is easy to accomplish by using transducers. Level changes result in the displacements of the top surface of the liquid. Many types of transducers may be used to measure liquid level. Resistive transducers may be used to measure the level of a conductive solution. A capacitive transducer may be used along with a movable plate whose position is determined by the level of the liquid. Photoelectric methods, radioactive methods, and ultrasonic methods may also be employed.

A simple type of level controller is the ball float system. This system uses a ball float to operate a lever. The lever is connected to a valve which regulates liquid flow rate. Chemical industries commonly use differential pressure controllers to control the level of volatile liquids. The liquid pressure is proportional to its level in the enclosed container.

Level control may be accomplished by placing a light source at the same height above a conveyor line as the desired fill level of a container. In the illustration of Figure 37-1 containers on a conveyor line are positioned under a liquid dispenser. When the container is in position, the actuator causes the dispenser to allow liquid to pass into the container. When the liquid reaches the level of the light source, the light beam is interrupted. With no light striking its surface, the detector will cause a relay to activate. The activated relay will, in turn, cause the actuator on the dispenser to close. When another container is in position, the actuator will open once more. This liquid level control system ensures a uniform level of liquid in each container. In this activity you will construct and test a photoelectric circuit which could be used to measure liquid level.

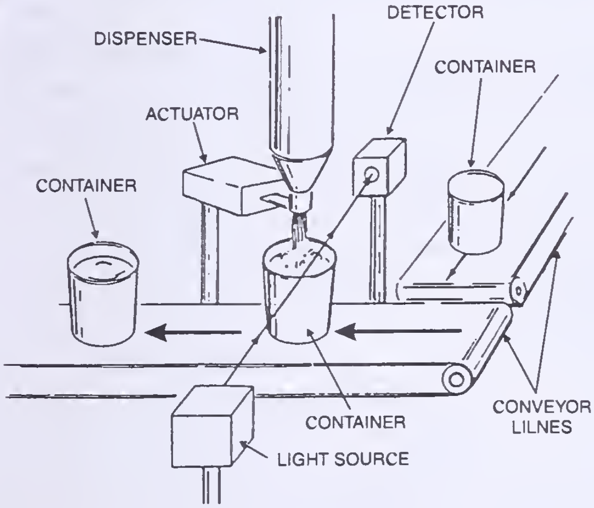


Figure 37-1 Method of liquid level control.

Equipment and Materials:

- Variable dc power supply.
- Light-dependent resistor (GE-X6 or equivalent).
- Electronic multifunction meter.
- Container (glass or plastic).
- 12v, 1250 Ω relay (Guardian 1335-2C-120D or equivalent).
- 60 W lamp with holder.
- 7 W lamp with holder.
- SPST switch.
- 120v ac power source.

Procedure:

1. Construct the photoelectric liquid level control of Figure 37-2.
2. Plug the light source into a 120v ac power outlet and close the circuit switch. Position the light source near the bottom of the glass container before it is filled with water. Slide the paper tube around the light-dependent resistor (ldr) and place the open end against the container.

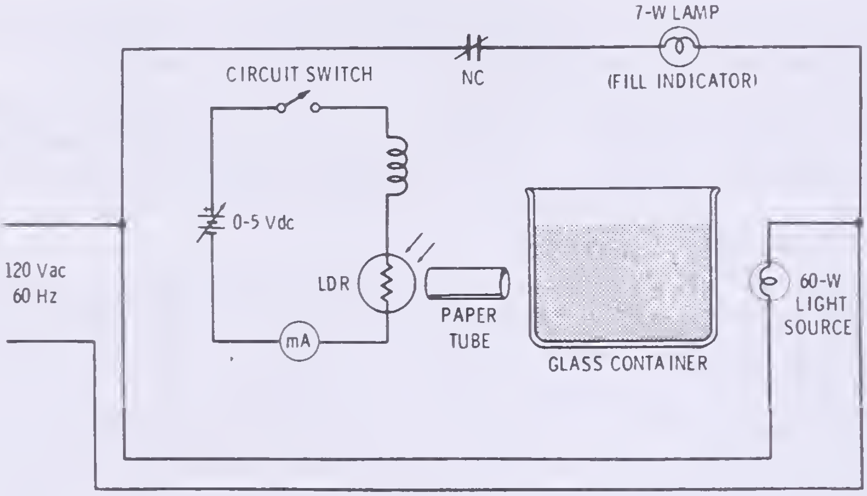


Figure 37-2 Photoelectric liquid level control.

3. If the circuit is operating properly, the fill indicator lamp will light when the relay is actuated.
4. Adjust the dc source to alter the sensitivity of the circuit. Do not exceed 15v dc. The circuit should be able to detect a pencil passing in front of the paper tube.
5. Carefully fill the container with water until the indicator turns off. Avoid pouring water directly in front of the tube window area. You may need to try several trial runs to get the sensitivity to a level where the circuit will respond properly.
6. After the sensitivity has been adjusted, drain or siphon water from the container until the fill indicator is actuated again.
7. Test the liquid level control circuit two or three times to ensure that it operates properly.
8. This concludes the activity. Disassemble and return all components to the storage area.

Analysis:

1. Discuss the operation of the circuit used in this activity.
2. What are some other types of circuits which could be used for liquid level control?

Activity 38—Proximity Detectors

Name ______________________________ Date ______________ Score __________

Objectives:

Proximity detectors are used to trigger an alarm or turn on a circuit by detecting physical change within a designated area. These circuits are designed to respond in some way to a change in capacitance. This change usually alters the frequency of an oscillator so that the output can be amplified and used to trigger a load control device. Typically the circuit contains an oscillator, a tuned circuit, an amplifier, and a trigger device.

One of the most popular proximity detectors in operation today utilizes the loaded oscillator principle. In this type of circuit, the LC components of the oscillator are shunted to ground by an external capacitance. This capacitance is usually called the *sensor plate*. Moving a hand or producing a physical change near the sensing plate upsets the electrostatic field of the capacitance. This in turn alters the frequency of the oscillator or may load down the circuit in such a way as to quench the oscillation process. Liquid level detection, automatic thickness gauge testers, intruder alarm systems, counters, and switching circuits employ this type of detector.

In this activity you will construct a loaded oscillator proximity detector. The oscillator is a Colpitts type with split capacitors in the collector circuit. The output of the oscillator is rectified and applied to a voltage comparator circuit where it is amplified by an op amp. The amplified output is used to trigger a load control device. The 5 kΩ resistor in the comparator circuit is used to establish a balanced condition for detection. When the oscillator senses a change, it loads down and stops oscillating. This creates an imbalance which is then detected by the comparator circuit.

Through this activity you will test the operation of a loaded oscillator circuit and observe typical waveforms. The test procedure used to analyze circuit operation is also used to troubleshoot the circuit. Through this testing experience you will become familiar with the oscillator loading principle and be able to follow a logical troubleshooting procedure.

Equipment and Materials:

- 0-10v, 1 A dc power supply.
- LM3900 op amp.
- 2N3397 transistor.
- 10 mH coil.
- 1N4004 diode.
- light-emitting diode.
- 0.1 µF, 200v dc capacitor.
- 0.01 µF, 100v dc capacitor.
- 100 pF, 100v dc capacitor.
- 47 pF, 100v dc capacitor.
- 1 MΩ, 1/4 W resistors (2).
- 68 kΩ, 1/4 W resistor.
- 10 kΩ, 1/4 W resistors (2).
- 6.8 kΩ, 1/4 W resistor.
- 5 kΩ, 2 W potentiometer.
- 1 kΩ, 1/4 W resistor.
- 470 Ω, 1/8 W resistor.
- 500 kΩ, 2 W potentiometer.
- SPST toggle switches (2).
- 6″ × 6″ sensor plate (metal).
- *Optional according to the selected load control circuit.*
- 2N3397 transistor.

- 12v, 125 Ω relay (Guardian 1335-2C-120D or equivalent).
- No. 47 lamp with socket.
- 47 Ω, 1/2 W resistor.
- SCR (General Electric C-122D or equivalent).
- 220 Ω, 1/2 W resistor.
- 6.3v, 60 Hz ac source.

Procedure:

1. Construct the proximity detector of Figure 38-1.

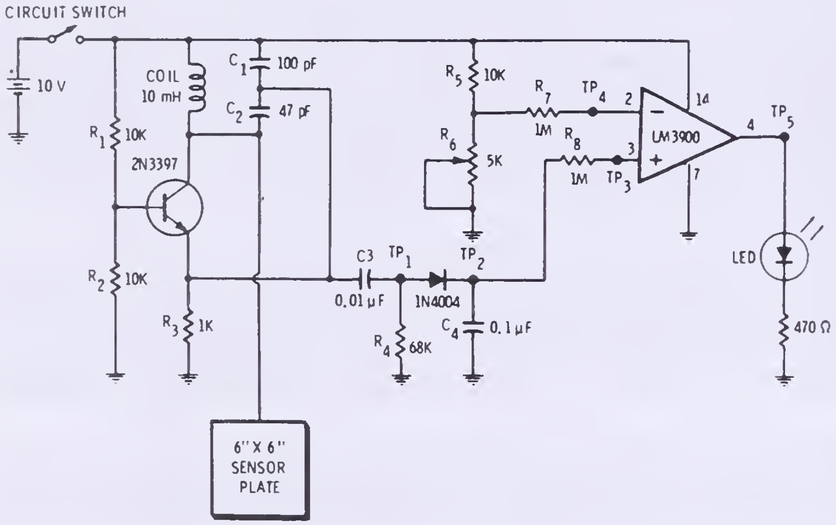


Figure 38-1 Proximity detector.

2. Close the circuit switch and adjust the 5 kΩ potentiometer for illumination of the LED. There should be a specific point where the LED turns on. Increasing resistance will cause it to remain on, while decreasing the resistance causes it to turn off. The point just before turn-on represents the most sensitive detection setting of the potentiometer. Adjust the potentiometer several times to locate the most sensitive point.

3. If the circuit is not operating properly, perform Steps 4, 8, 9, 10, and 11 first to determine which part of the circuit is malfunctioning. If the circuit is operating satisfactorily, follow the procedure steps in order and record the indicated data.

4. Prepare an oscilloscope for operation and connect it to test point 1. Make a sketch of the observed waveform, Figure 38-2.

5. While observing the oscilloscope, touch the sensor plate. What influence does this have on the waveform?

6. Move your hand over the sensor plate while observing the oscilloscope. What influence does this have on the waveform?

7. Determine the frequency of the oscillator with the oscilloscope or a frequency meter.

   Oscillator frequency = __________ Hz.

Figure 38-2 Observed waveform at test point

8. Measure and record the voltages at the emitter-base and collector of the oscillator transistor Q_1.

   Emitter voltage = __________ v.

Name ____

Base voltage = __________ v.

Collector voltage = __________ v.

Compare your measurements with those indicated on the schematic diagram.

9. Measure and record the dc output voltage at test point 2.

   Unloaded oscillator output voltage = __________.

10 Touch the sensor plate and record the measure voltage at test point 2. This represents the loaded output voltage of the oscillator.

   Loaded output voltage = __________ v.

   The output of the oscillator will change approximately 2 v between the loaded and unloaded conditions of operation.

11. Measure and record input voltages at TP_3 and TP_4 when the LED is on. This indicates a balanced condition.

   TP_3 = __________ v.

   TP_4 = __________ v.

12. Measure and record the voltages at TP_3 and TP_4 when the circuit is unbalanced.

   TP_3 = __________ v.

   TP_4 = __________ v.

13. Measure and record the output voltage of the circuit at test point TP_5 for the balanced and unbalanced conditions. The total change in voltage is __________ v.

14. Select one of the alternate load control circuits in Figure 38-3 and construct it. Connect it to the output of the proximity circuit.

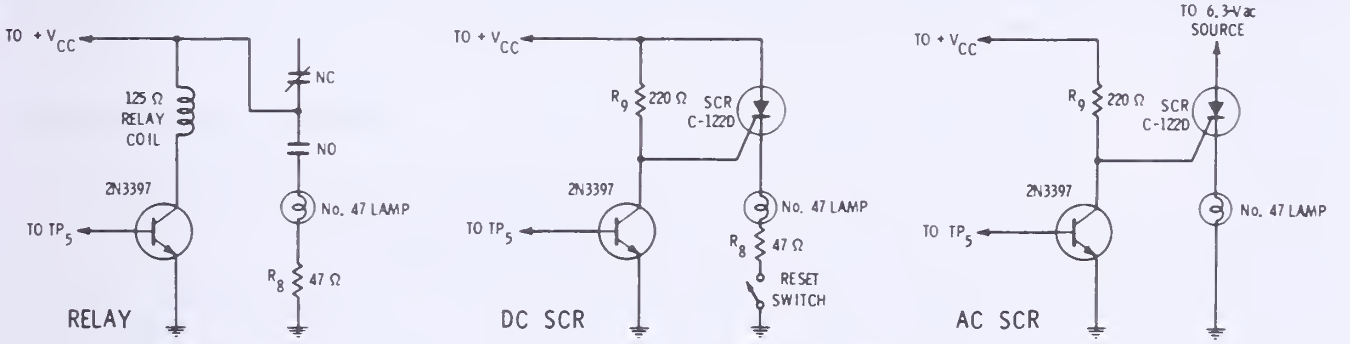


Figure 38-3 Alternate load control circuit.

15. Close the circuit switch, adjust the balance potentiometer, and test the control capability of the completed load control circuit.

16 Open the circuit switch. Disconnect the circuit and return all parts to the storage area.

Analysis:

1. Describe what is meant by loaded and unloaded oscillator conditions.

____

____

____

2. What is the function of the IC op amp in the proximity circuit of Figure 38-1?

3. Draw a block diagram representing the major parts of the proximity circuit constructed in Step 15.

Activity 39—LVDT Detector

Name ______________________________ Date ______________ Score __________

Objectives:

Frequently, it is not enough to measure only the amount of the displacement of an object. Often the direction of displacement, as well as the amount of displacement, must be indicated. When this becomes the case, a detector circuit similar to that shown in Figure 39-1 can be used in conjunction with the output of the **light variable displacement transformer**.

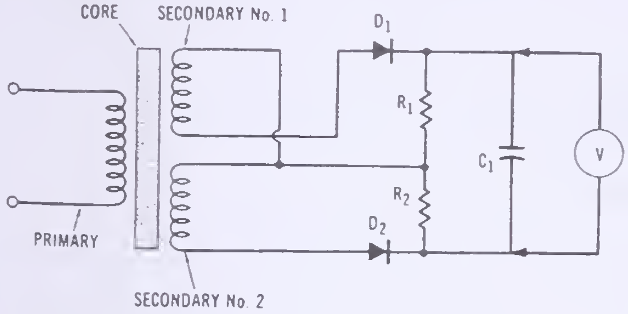


Figure 39-1 LVDT detector circuit.

In this detector circuit, the diodes conduct equally when the movable core is in the null position. This results in an equal and opposite voltage drop across R_1 and R_2, causing the readout device (voltmeter) to indicate zero displacement. When displacement occurs, one diode will conduct more than the other, causing an upset in the balanced voltage across R_1 and R_2. The result is an output voltage, as measured by the voltmeter, whose polarity indicates the direction of displacement and whose magnitude indicates the amount of displacement. In this activity you will examine a detector circuit used with the LVDT constructed in the previous activity.

Equipment and Materials:

- Digital multimeter.
- Air-core coils, 100 turns, A.S. No. 16 wire (2).
- Air-core coil, 200 turns, A.S. No. 24 wire.
- 6″ (15 cm) steel core, 3/4″ (1.91 cm) diameter.
- 6v ac power supply.
- 1N4004 diodes (2).
- Resistors: 1 kΩ (2).
- Capacitor: 1 μF, 25 vdc.
- Connecting wires.
- SPST switch.

Procedure:

1. Construct the circuit illustrated in Figure 39-2.
2. Close the SPST switch and slide the movable core until the voltmeter indicates zero.
3. Moving the core in the direction and by the amount indicated in Figure 39-3, complete the table by recording the voltage output of the detector circuit along with the proper voltage polarity.
4. How do the voltages generated by moving the core to the left compare with the voltages generated when the core is moved to the right?

____

____

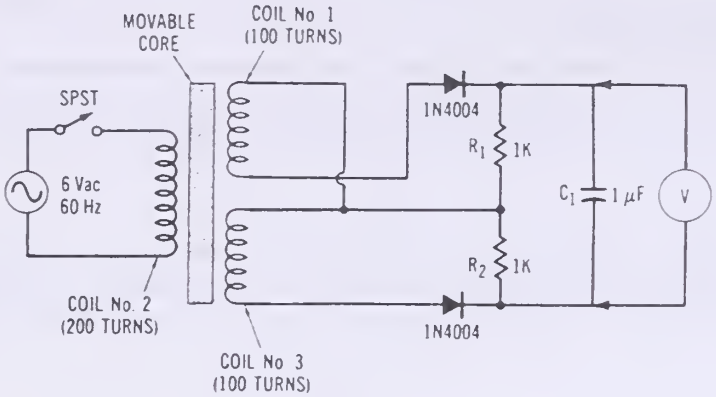


Figure 39-2 LVDT detector test circuit.

Direction of Movement from Null Position	Amount of Movement Inches	Centimeters	Voltage Output	Polarity (+ or –)
Left	1/16	0.159		
Left	1/8	0.318		
Left	3/16	0.477		
Left	1/4	0.635		
Left	5/16	0.793		
Left	3/8	0.953		
Return to Null Position				
Right	1/16	0.159		
Right	1/8	0.318		
Right	3/16	0.477		
Right	1/4	0.635		
Right	5/16	0.793		
Right	3/8	0.953		

Figure 39-3 Output polarity and magnitude of LVDT test circuit.

5. Ideally, what is the minimum displacement of the movable core that would result in a voltage output?

Analysis:

1. What is meant by coils being connected in series to oppose?

2. Explain how the detector circuit used in conjunction with the LVDT enables the direction of displacement to be measured.

Name ____

3. When is it necessary to measure direction, as well as amount of displacement?

____

____

4. How would the null position of the core be affected if R_1 of the detector circuit were a value different from R_2?

____

____

Activity 40—Photoelectric Sensors

Name ______________________ Date ______________ Score ________

Objectives:

Photoconductive sensors are designed to produce changes in their electrical conductivity when variations of light energy occur. These devices are also called *photoresistive*, since their resistance varies in inverse proportion to their conductivity. The cadmium sulfide (CaS) cell, shown in Figure 40-1, is a common type of photoconductive cell. When exposed to varying intensities of visible light, the cadmium sulfide cell will change resistance. An increase in light energy falling onto its surface will increase the conductivity of the cell. The cell is highly sensitive to variations of light intensity. It is typically used in alarm and relay control systems.

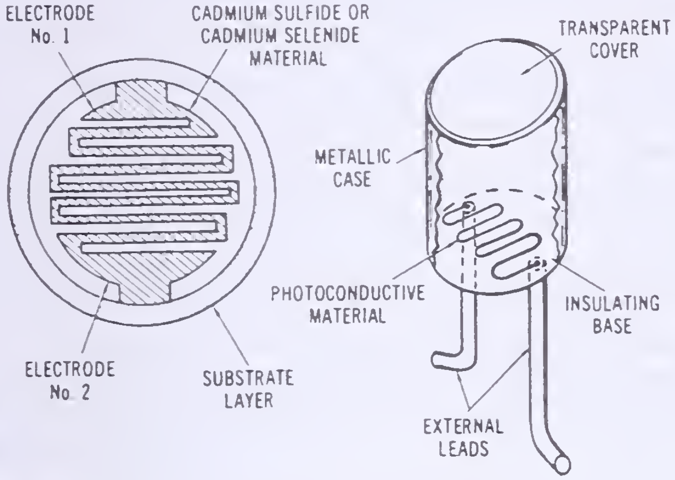


Figure 40-1 Cadmium sulfide photoconductive cell.

When light strikes the surface of a photoconductive cell, valance electrons of the semiconductor material are released from their atomic bonds. When electrons are released, the resistance of the material decreases. We may also say that the material becomes more conductive. If the light intensity is increased, more electrons will be released and the material becomes more conductive. Resistance of photoconductive devices may range from several megohms in darkness to 50-100 Ω in fairly intense light. In this activity you will observe the characteristics of a photoconductive cell. The photoconductive cell is a popular type of photoelectric transducer.

Equipment and Materials:

- Photoconductive cell: GE-X6.
- Variable ac power supply.
- Multifunction meter
- Lamp: 60 W.
- Connecting wires.

Procedure:

1. Assemble the circuit shown in Figure 40-2. Connect the meter across the photoconductive cell so that it will measure resistance changes with changes in light intensity. The 60 W lamp is connected to a 0-120v ac power source.
2. Record the resistance of the photoconductive cell with room light.

   R = __________ Ω

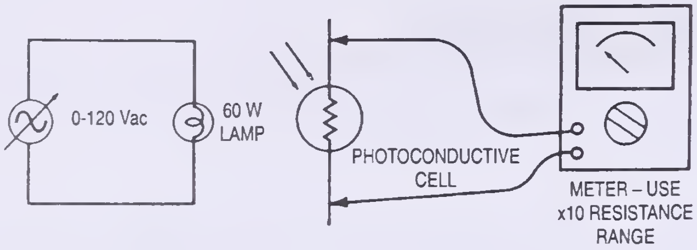


Figure 40-2 Photoconductive cell test circuit.

3. Cover the top of the cell with your finger and record the resistance without light.

   R = __________Ω

Light Source Voltage	Resistance (Ω)
0	
10	
20	
30	
40	
50	
60	
70	
80	
90	
100	
110	
120	

Figure 40-3 Photoconductive cell characteristics.

4. Place the 60 W lamp within 1/2″ (1.27 cm) of the top of the cell. Adjust the variable ac source to zero volts.
5. Turn on the ac source and complete the table in Figure 40-3 by adjusting the source voltage as indicated.
6. This concludes the activity. Disassemble and return all components to the storage area.

Analysis:

1. What is the range of resistance change of the photoconductive cell used in this activity?

   Range = __________ to __________ Ω
2. Discuss the characteristics of a photoconductive cell.

Activity 41—Temperature Sensors

Name ______________________________ Date ______________ Score __________

Objectives:

Temperature sensing circuits are widely used in industry as system control elements. Heat sensors, which are by far the most popular of all sensors, are commonly found in alarm circuits that detect changes in temperature at remote locations. Machinery, electronics equipment, and measuring instruments also employ temperature sensors to detect unusual operating conditions. The thermistor is a very popular sensor element for temperature detection equipment.

Thermistors are primarily classified as temperature sensitive resistors with an operating range of from -382°F (-230°C) to 1202°F (650°C). When used in bridge circuits with high-gain amplification, thermistors can detect temperature changes as small as 0.001°.

The physical makeup of a thermistor includes a mixture of nickel, manganese, and cobalt oxides formed into a piece of semiconductor material. These oxides are mixed together and fired to form a coherent nonporous material. The mixture is then formed into a variety of shapes. In this activity a tiny piece of the ceramic material is formed into a bead and enclosed in glass. Changes in temperature cause the resistance of the thermistor to produce a wide range of values. Typically, thermistors have a negative temperature coefficient. This means that an increase in temperature causes a decrease in resistance. Metal, by comparison, has a positive temperature coefficient. This means that a rise in temperature causes a corresponding increase in resistance.

In this activity you will build a temperature detecting bridge circuit. The output of the bridge is then fed into an op amp for high-gain amplification and increased sensitivity. Any imbalance in the bridge is detected by the amplifier and is used to trigger an output circuit. Circuits of this type are typically found in alarm circuits that function as heat detectors.

Equipment and Materials:

- Split dc power supply: ±9v at 1 A, or two 9v batteries.
- µA741C op amp.
- Thermistor (Fenwal gB 32J2 or equivalent).
- 200 kΩ, 1/4 W resistor.
- 10 kΩ, 1/4 W resistors (2).
- 5 kΩ, 2 W potentiometer.
- 2.7 kΩ, 1/4 W resistors.
- 1 kΩ, 1/4 W resistor.
- 47 Ω, 1/4 W resistor.
- No. 47 lamp with socket.
- IC circuit construction board.
- SCR (GE C-122D or equivalent).
- Electronic multifunction meter.
- Decade resistance box (optional).
- SPST toggle switch.

Procedure:

1. Construct the thermistor bridge circuit of Figure 41-1. Note that a voltmeter is used to detect the amplified output of the circuit.
2. Before connecting the thermistor into the circuit, measure its resistance. Try to avoid touching the glass part of the thermistor when attaching the test leads. With the ohmmeter connected, the resistance should stabilize after a few seconds. The stabilized resistance is __________ Ω.

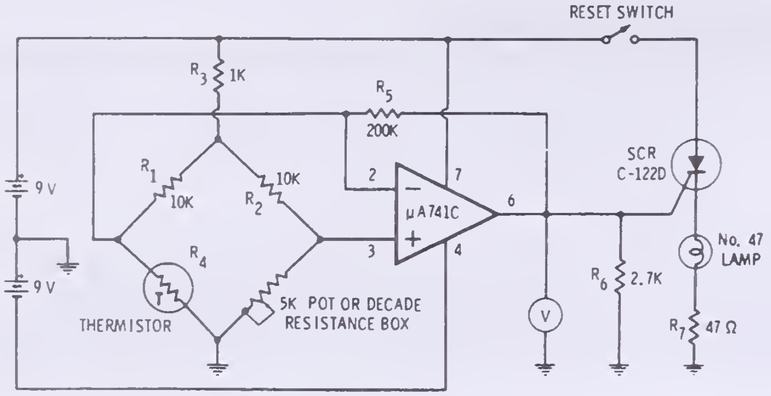


Figure 41-1 Thermistor bridge circuit.

3. While observing the ohmmeter, grasp the glass bead between your index finger and thumb. How does body temperature influence the resistance of the thermistor?
4. Connect the thermistor to the bridge circuit as indicated. The reset switch should be in the off position and the electronic multifunction meter should be adjusted to the zero center position. It should be in the 50v or equivalent range.
5. Turn on the split power supplies and energize the circuit. Balance the bridge by adjusting the potentiometer to produce a zero indication on the meter. A decade resistance box can be used in place of the potentiometer.
6. After the bridge has been nearly balanced, you may switch the voltmeter to a lower range to improve the balancing accuracy.
7. To test the sensitivity of the circuit, place your finger near the glass bead of the thermistor while observing the voltmeter. If the circuit is working properly, the meter should deflect upscale or in the positive direction. Within a few seconds it should return to the balanced indication when the thermistor has reached its stabilized resistance. If you touch the glass bead with your finger, it usually takes longer for it to return to the balanced state.
8. You may want to try blowing on the thermistor or placing it near some heat producing source. Avoid temperatures over 302°F (150°C).
9. Close the reset switch of the SCR. Place your finger near the thermistor. While observing the voltmeter, see how much voltage is needed to trigger the SCR into conduction. You must wait a few seconds for the thermistor to stabilize before resetting the SCR.
10. Try several sources of heat to turn on the sensor circuit.
11. Turn off the power supply and disconnect the circuit. Return all components to the storage area.

Analysis:

1. What type of temperature coefficient does the thermistor used in this activity have?

2. Explain how a change in thermistor resistance causes the bridge circuit to be imbalanced.

3. Why is it advantageous to use an op amp with the bridge circuit of this activity?

Activity 42—Thermocouple Applications

Name ______________________________ Date ________________ Score __________

Objectives:

Thermocouples are frequently used to measure temperatures in an industrial setting. Due to the relatively low voltage output associated with most thermocouples, amplification circuits are used to increase this output as well as to increase sensitivity. The resulting output of the amplification circuit is used to drive or activate a readout device.

In this activity you will see the thermocouple used to control the conductivity of an FET. The conductivity of the FET, in turn, controls the action of a single stage transistor amplifier and thus the current flow through a multimeter that is used as the readout device.

Equipment and Materials:

- Type J thermocouple.
- Digital vom.
- Resistors: 560 Ω, 5.6 kΩ.
- 0-5v dc power supply.
- 10v dc power supply.
- GE-FET-1 field-effect transistor.
- 2N2405 npn transistor.
- Connecting wires.
- 660 W heat cone.
- 120vac power supply.

Procedure:

1. Construct the circuit shown in Figure 42-1.

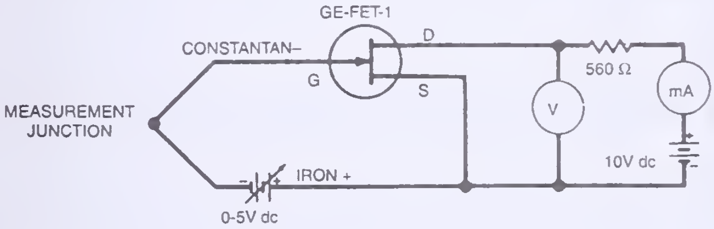


Figure 42-1 Type J thermocouple FET circuit.

2. Allow the measurement junction of the thermocouple to remain at room temperature. Alter the gate voltage of the FET to equal those listed in Figure 42-2. Record the source drain current and voltage for each FET gate voltage value.
3. Adjust the gate voltage to 0.2v.
4. Grasp the measurement junction of the thermocouple between your thumb and forefinger. Describe how this action affects the source drain current and voltage of the FET as compared to the data gathered in Step 2 when the gate voltage was 0.2v.

   ____

   ____

5. Connect the 660 W heat cone to 120v ac and allow it to warm up for about 3 minutes.

Gate Voltage (V)	Source-Drain Current (mA)	Source-Drain Voltage (V)
0.2		
0.4		
0.6		
0.8		
1.0		
1.5		
2.0		

Figure 42-2 Thermocouple-controlled FET circuit data.

6. Position the measurement junction of the thermocouple inside the heat cone for a period of 3 minutes and record the source drain current and voltage of the FET.

   I_{sp} = __________; V_{sp} = __________

7. How does the values of source drain current and voltage recorded in Step 6 compare with the data gathered in step 2 when the FET gate voltage was 0.2v dc?

8. Disconnect the heat cone from the 120v ac power supply. What effect does the removal of the heat cone have upon the source drain current and voltage?

9. Construct the circuit illustrated in Figure 42-3.

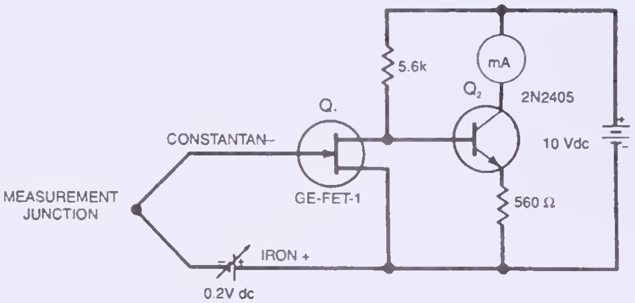


Figure 42-3 Type J thermocouple transistor circuit.

10. Record the collector current of Q_2 as displayed by the digital vom with the measurement junction of the thermocouple at room temperature.

    I_c = __________

Name ______________________________

11. Grasp the measurement junction of the thermocouple between your thumb and forefinger. Describe how this action affects the collector current of Q_2 as displayed on the digital vom.

____

____

12. Place the measurement junction of the thermocouple inside the cone of the *cool* 660 W heater. Connect the 120 vac to the heat cone and allow it to warm up for 5 minutes.

13. Record the collector current of Q_2 as displayed on the digital vom after the heat come has warmed up.

I_c = __________

14. How does the current recorded in Step 10 compare with the current recorded in Step 13?

____

____

15. How do you explain the difference?

____

____

16. If the digital vom used in the circuit shown in Step 9 were calibrated in degrees Fahrenheit, how could the circuit be used to measure temperature?

____

____

17. Disassemble and return all components to the storage area.

Analysis:

1. Why is it sometimes necessary to use an amplifier when a thermocouple is used to measure temperature?

____

____

2. What was the readout device used in the circuit in Step 9?

____

3. What would determine the maximum temperature that could be measured by the circuit in Step 9?

____

____

4. How did the action of the circuit used in Step 9 differ from that used in Step 2?

____

____

5. Explain how the circuit in Step 2 could be used to measure temperature.

____

____

Activity 43—Solenoids

Name ______________________________________ Date __________________ Score ___________

Objectives:

A solenoid is an electromagnetic coil with a movable core constructed of a magnetic material. The core or plunger, is sometimes attached to an external spring. This spring causes the plunger to remain in a fixed position until moved by the electromagnetic field created by current applied to the coil. This external spring also causes the core or plunger to return to its original position when the coil is deenergized.

Solenoids are used for a variety of applications. Most door chime circuits use one or more solenoids to cause the chime to sound. Many gas and fuel oil furnaces use solenoid valves to automatically turn on or off the fuel supply upon demand. Most dishwashers use one or more solenoids to control the flow of water.

In this activity you will learn the basic operation of the solenoid. You will observe the solenoid as it is used to operate door chimes.

Equipment and Materials:

- Volt-ohm-milliammeter (vom).
- Door chimes (low voltage, 6 to 24v).
- Variable dc power supply.
- Air-core coil (200 turns, No. 24 wire) or equivalent.
- Cold-rolled steel core, 3/4″ diameter, 6″ long or suitable substitute.
- SPST switch.
- Connecting wires.

Procedure:

1. Adjust the vom to measure resistance. Measure and record the resistance of the air-core coil to be used in this activity.

   __________ Ω

2. Connect the circuit shown in Figure 43-1.

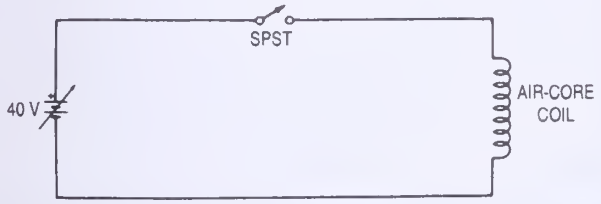


Figure 43-1 Solenoid test circuit.

3. Place about 2 inches of the end of the cold-rolled steel bar into the coil (see Figure 43-2).
4. Close the SPST switch and describe what happens to the cold-rolled steel core. **To prevent the coil from heating do not allow the SPST switch to remain closed for over 20 seconds.**

   ____

   ____

5. Place the bar inside the coil and close the SPST switch. Try to remove the bar with the power on. Describe what happens. **Do not allow the coil to remain energized for more than 20 seconds.**

   ____

   ____

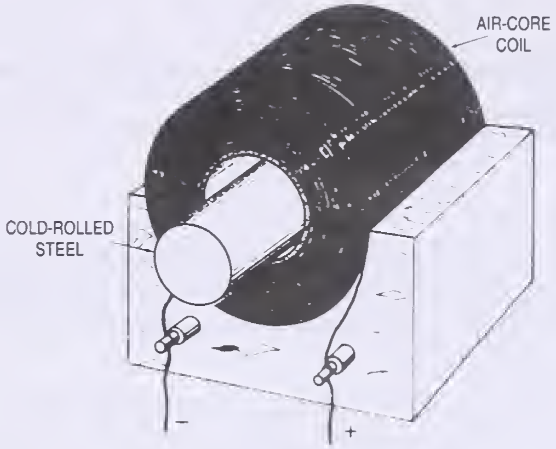


Figure 43-2 Air core coil and steel core.

6. How could the above solenoid be used as a pusher or puller coil?

7. Disconnect the circuit in Figure 43-1.

8. Acquire a door chime assembly. Examine it to determine if it is to be powered by 6, 12, 18, or 24 volts. Indicate the voltage used for the chime assembly in the space below.

   __________ v

9. Remove the protective chime cover to expose the spring-loaded solenoids and solenoid connections. Measure and record the resistance of the solenoid coil in the space below.

   R = __________ Ω

10. There should be three solenoid connections. One will be common to the other two. Connect the common connection and either of the remaining connections to the power supply as shown in Figure 43-3.

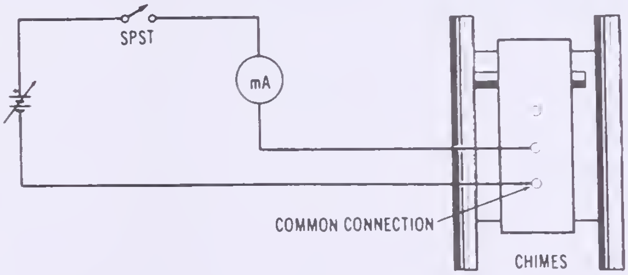


Figure 43-3 Solenoid circuit from Figure 43-1 with door chime.

11. Close the SPST switch and slowly adjust the power supply from zero until the plunger of the solenoid is drawn into the core. Record the current necessary to pull the plunger.

    __________ A

12. Open the SPST switch, adjust the power supply to the voltage indicated in step 8.

13. Open and close the SPST switch several times. Describe what happens.

14. Disconnect the circuit and return all components to the storage area.

Name ______________________________

Analysis:

1. What is a solenoid?

2. Where are solenoids used?

3. Why are solenoids sometimes called pusher coils?

4. Why are solenoid plungers spring-loaded?

Activity 44—Control Systems Overview

Name ______________________________ Date ______________ Score __________

Objectives:

The term **system** is commonly defined as an organization of parts that are connected together to form a complete operating unit. In this respect it can apply to a variety of different systems used by industry to achieve some operation in the manufacturing process. An application of this term is the industrial electronic system. Further application of this term includes a wide variety of sub systems under the heading of industrial electronics. Optoelectronic systems, timing systems, digital systems, and environment control systems are all included in this study of industrial systems.

Each industrial system includes a number of unique features or characteristics that distinguishes it from other systems. More importantly, however, there are a number of basic functions common to all electronic systems. **Energy source, transmission path, control, load,** and **indicator** are terms commonly used to describe these basic system functions.

In this activity you will have an opportunity to study a representative system and pick out the basic parts of the system. By doing this, you will become more familiar with the systems concept and be able to apply it to a specific situation.

Procedure:

1. Briefly define the function of the following basic system parts. Use general terms that would apply to all basic industrial electronic systems.

   Energy source.

   ____

   ____

   Transmission path.

   ____

   ____

   Control.

   ____

   ____

   Load.

   ____

   ____

   Indicator.

   ____

   ____

2. Explain how the systems concept could be applied to an electrical power system used to supply an industrial plant site.

   ____

   ____

3. How could the systems concept be applied to the simple electrical circuit of Figure 44-1?

   ____

   ____

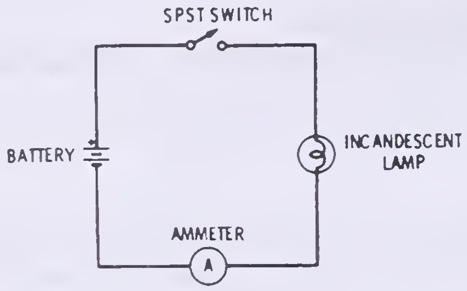


Figure 44-1 Electrical circuit.

4. The photoelectric box counter in Figure 44-2 is a typical industrial system. What are the basic parts of this system?

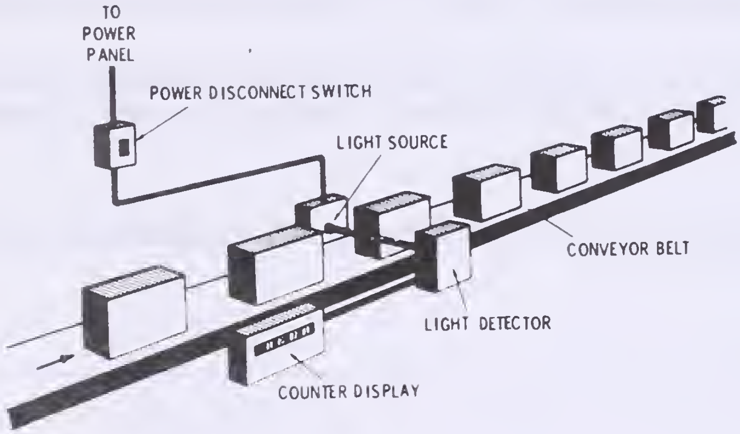


Figure 44-2 Industrial electronic system.

Analysis:

1. Of what significance is the basic systems concept in industry?

2. What is an opto-electronic system?

3. What are some applications of an industrial timing system?

4. What is meant by the term "digital system?"

5. What are some typical applications of an industrial environment system?

Activity 45—Digital Logic Functions

Name ______________________________ Date ______________ Score __________

Objectives:

Control of a digital system is achieved by a variety of logic gates. Each gate has a particular output response to a combination of input signals. Binary data is represented by 1s and 0s. Multiple-input gates of the AND and OR variety and a single input-output NOT gate represent the three primary logic functions of a digital system. An understanding of these logic functions is essential when analyzing the operation of a digital system.

In this activity each basic logic gate will be constructed with a single integrated circuit. Truth tables will then be developed to show the relationship between the input alternatives and the corresponding output. Through this activity you will gain experience in using the basic logic gates and see how the logic functions are achieved electronically.

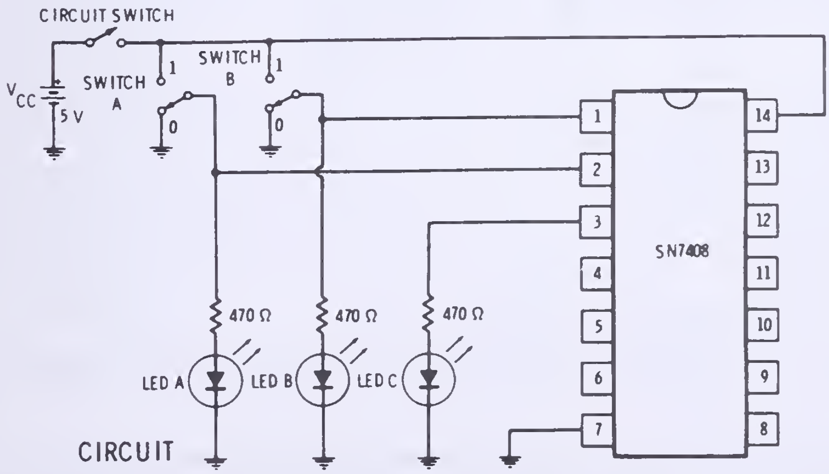
Equipment and Materials:

- SN7408 IC.
- SN7411 IC.
- SN7432 IC.
- SN7404 IC.
- 5v dc power supply.
- 470 Ω, 1/8 W resistors (4).
- Light-emitting diodes (4).
- SPDT toggle switches (3).
- SPST toggle switch.
- IC breadboard construction unit.
- Multimeter.

Procedure:

Part A: Gate Testing With the SN7408 and SN7411

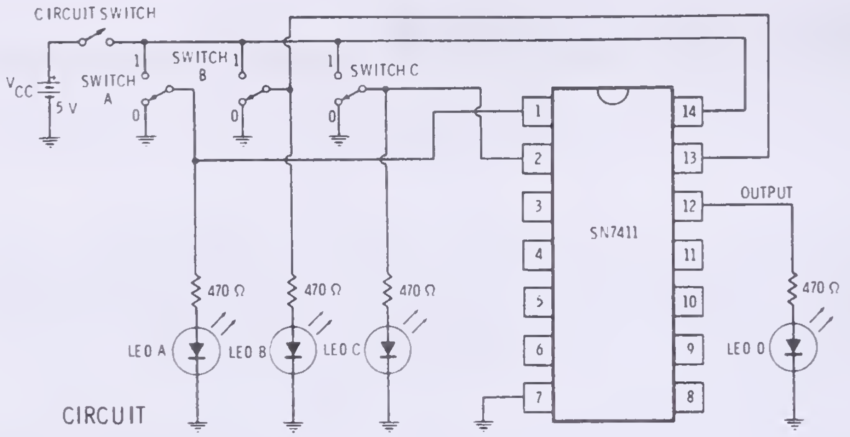
1. Connect the logic gate test circuit of Figure 45-1.
2. Before closing the circuit switch, turn on the power supply and adjust it to 5v.
3. Turn on the circuit switch and test the IC gate according to the alternatives listed in the truth table of Figure 45-2.



TRUTH TABLE

LED		
A	B	C
0	0	
0	1	
1	0	
1	1	

Figure 45-1 SN7408 IC test circuit and truth table.



TRUTH TABLE

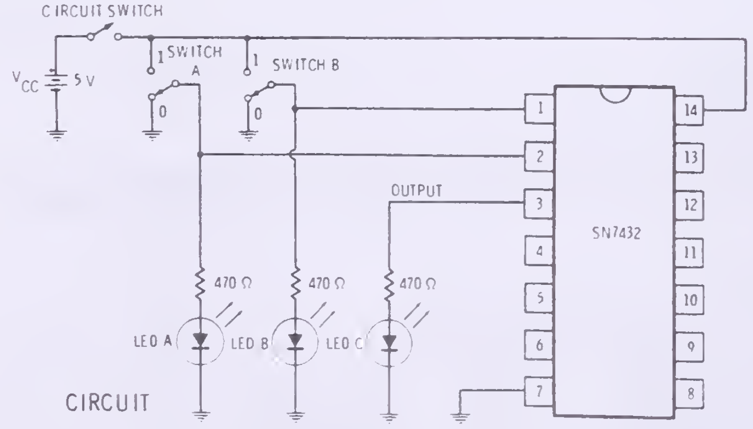
LED			
A	B	C	D
0	0	0	
0	0	1	
0	1	0	
0	1	1	
1	0	0	
1	0	1	
1	1	0	
1	1	1	

Figure 45-2 SN7411 IC test circuit and truth table.

4. Prepare a multimeter to measure voltage and determine the corresponding input and output voltages corresponding to 1 and 0.
5. There are three other gates included in this IC chip. Pins 4 and 5 are the input and pin 6 is the output of gate 2. Pins 9 and 10 are the input and pin 8 is the output of gate 3. Pins 13 and 12 are the input and pin 11 is the output of gate 4. Test these gates to see if they are working properly.
6. Make a gate symbol drawing on the blank IC dual in-line package layout of Figure 45-2 for the SN7408.
7. Open the circuit switch and remove the SN7408. In its place connect an SN7411. Be certain that pin 14 is connected to the +5v v_{cc} source and pin 7 is connected to ground. Connect the remainder of the circuit indicated in Figure 45-2.
8. Close the circuit switch and test the SN7411. Complete the truth table for the listed input alternatives.
9. Open the circuit switch and disconnect the IC.

Part B: Gate Testing With the SN7432

1. Construct the logic gate test circuit which is shown in Figure 45-3.



TRUTH TABLE

LED		
A	B	C
0	0	
0	1	
1	0	
1	1	

Figure 45-3 SN7432 IC test circuit and truth table.

2. Before closing the circuit switch, turn on the power supply and adjust it to 5v.
3. Turn on the circuit switch and test the IC gate according to those alternatives which are listed in Figure 45-3.
4. What logic gate function is achieved by this gate?
5. There are three other gates included in this IC chip: pins 4 and 5 are inputs; pin 6 the output; pins 9 and 10 are inputs; pin 8 is an output; and pins 12 and 13 are inputs; pin 11 the output. Test these gates to see if they are working properly.

Name ______________________________

6. Make a gate symbol drawing on the blank IC dual in-line package layout of Figure 45-4 showing the input output connections for the SN7432.

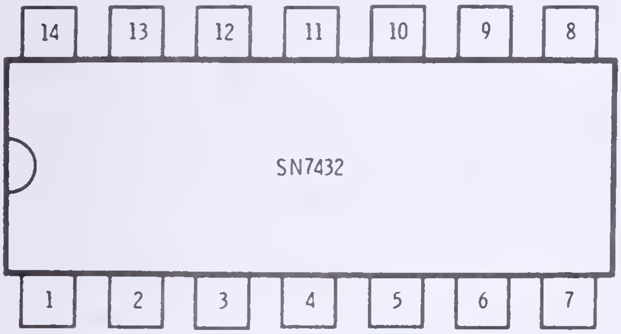
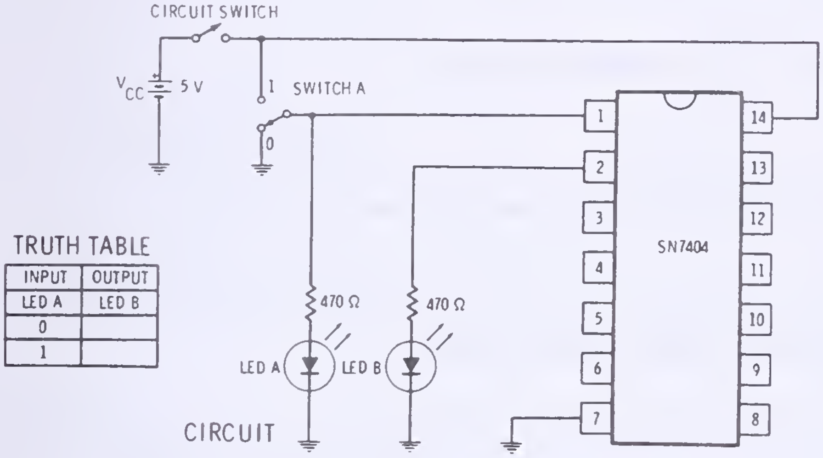


Figure 45-4 SN7432 IC pin connections.

7. Open the circuit switch and disconnect the circuit.

Part C: Gate Testing With the SN7404

1. Connect the logic gate test circuit of Figure 45-5.



TRUTH TABLE

INPUT	OUTPUT
LED A	LED B
0	
1	

Figure 45-5 SN7404 IC test circuit and truth table.

2. Before closing the circuit switch, turn on the power supply and adjust it to 5v dc.
3. Then close the circuit switch and test the IC gate according to the alternate input conditions listed in the truth table of Figure 45-5. Record the respective output for each of the inputs.
4. What logic function is achieved by this gate?
5. Test the remaining five gates at pins 3-4, 5-6, 9-8, 11-10, and 13-12. (The pin number designation listed first is the input, with the last number indicating the output.)
6. Make a gate symbol drawing on the blank dual inline package layout of Figure 45-6 showing the input-output connections for each gate of the SN7404.
7. Open the circuit switch and connect the output of gate 1 to the input of gate 2. Connect the output indicating LED to pin 4.
8. Close the circuit switch and test the logic circuit. What function does this indicate?

____

____

9. Open the circuit switch and disconnect the circuit. Return all parts to the storage area.

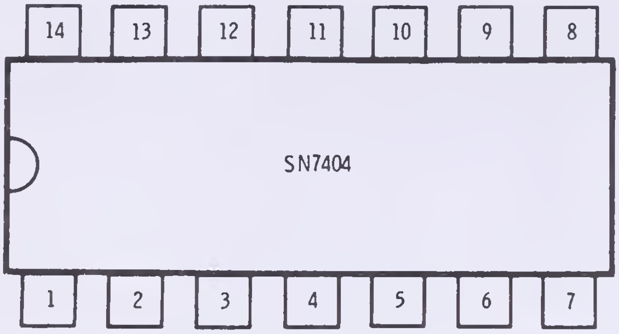


Figure 45-6 SN7408 IC pin connections.

Analysis:

1. What logic functions are achieved by the gates studied in Part A?

2. What mathematical functions are achieved by the gates studied in Part A?

3. What are the symbolic representations of the gates studied in Part A?

4. Prepare a statement that describes the operation of the gates studied in Part A.

5. What mathematical function is achieved by the gate studied in Part B?

6. What are the two logic symbols that are used to represent the circuit constructed in Part B of this activity?

7. Prepare a statement that describes the operation of the gate studied in Part B.

8. What mathematical function is achieved by the logic gate studied in Part C?

9. What is meant by the terms "negation" and "double negation?"

10. What would be the resulting output of a 1 applied to three of the gates studied in Part C of this activity connected in series?

Activity 46—Combination Logic Gates

Name ______________________________ Date ______________ Score __________

Objectives:

When either an AND gate or an OR gate is connected to a NOT gate, two additional logic functions are achieved. A NOT-AND, or NAND, is one type of combination logic gate. The NOT-OR, or NOR, gate is representative of the second type of combinational logic gate achieved.

NOR, NAND, and NOT gates are often considered to be universal building blocks in digital systems. With these gates, it is possible to build four logic gates plus the original function. A person working with digital systems should be very familiar with the universal building block principle of combinational logic gates.

In this activity you will investigate the NAND, NOR, and NOT gates in combinational logic gate construction operations. Only gates that have an inverting capability can be used in this building block technique.

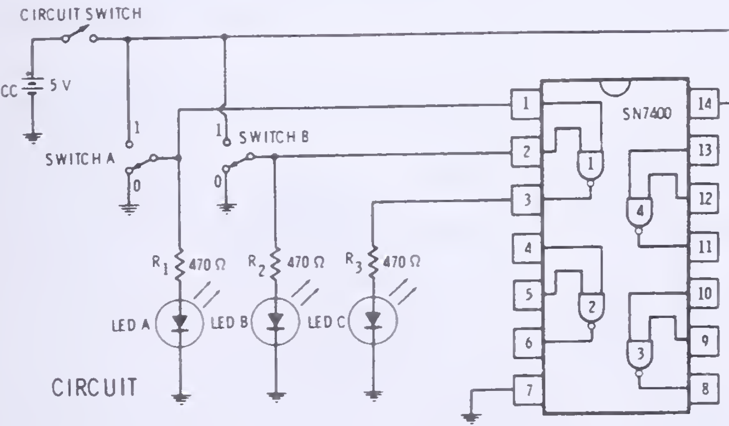
Equipment and Materials:

- SN7400 IC.
- SN7402 IC.
- SN7404 IC.
- SPST toggle switch.
- SPDT toggle switches (2).
- 470 Ω, 1/8 W resistors (3).
- Light-emitting diodes (3).
- 0-5v dc, 1 A power supply.
- Multimeter.
- IC circuit construction board.

Procedure:

Part A: NAND Logic

1. Using the SN7400 quad NAND of Figure 46-1, build the IC test circuit and check gate 1.



TRUTH TABLE

GATE 1		
INPUTS		OUTPUT
A	B	C
0	0	
0	1	
1	0	
1	1	

Figure 46-1 SN7400 IC test circuit and truth table.

2. Record the 1s and 0s of the output in the truth table for each of the input alternatives.
3. With a multimeter, measure and record voltage values represented by the 1s and 0s of this gate.

A 1 = __________v, while a 0 = __________v.

4. Test the other three gates to make certain that they are functioning properly.
5. To build a NOT gate, remove the B circuit from pin 2 and connect pins 1 and 2 together. Use switch A as the input and test the output of the gate.
6. Connect NAND gate 1 as instructed in procedure Steps 1 and 3. Connect the output of gate 1 to pins 4 and 5 of NAND 2. Connect the output LED to pin 6. What function does this combination logic gate achieve?

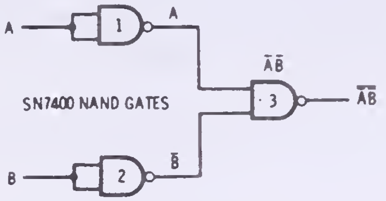
____

____

7. Test the circuit to verify your theory. Did it work as you predicted?

____

8. Connect the combinational logic circuit of Figure 46-2. Complete the truth table showing the outputs at the indicated points.



INPUT		EXPRESSION			OUTPUT
A	B	$\bar{A}$	$\bar{B}$	$\bar{A}\bar{B}$	$\overline{\bar{A}\bar{B}}$
0	0				
0	1				
1	0				
1	1				

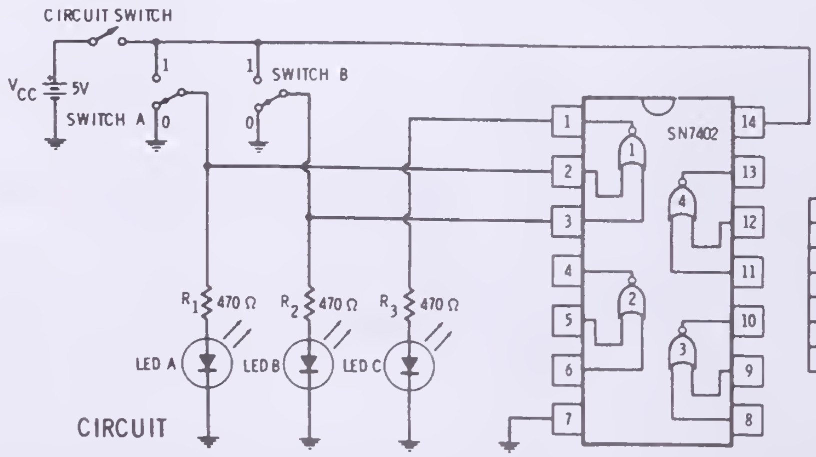
Figure 46-2 Combination NAND gate circuit and table.

9. According to the truth table, what gate function is achieved by this combination logic gate? Test the gate to verify your prediction. Did it perform the function that you expected?

____

Part B: NOR Logic

1. Using an SN7402 quad NOR gate, Figure 46-3, build the IC test circuit and check gate 1.
2. Record the 1 and 0 outputs for the input alternatives listed in the truth table in Figure 46-3.



TRUTH TABLE

GATE 1		
INPUTS		OUTPUT
A	B	C
0	0	
0	1	
1	0	
1	1	

Figure 46-3 SN7402 IC test circuit and truth table.

3. With a multimeter measure the voltage values represented by the 1s and 0s of this gate.
4. Test the other three gates to make certain that they are functioning properly.

Name ______________________________

5. To build a NOT gate, disconnect the lead to pin 3 and then connect pin 2 to pin 3. Use switch A as the input and test the output of the gate.
6. Connect NOR gate 1 as instructed in Steps 1 and 2. Connect the output of NOR 1 to the input of NOR 2, with NOR 2 connected as a NOT gate. Connect the output LED to pin 4. What combination logic is achieved by this configuration?

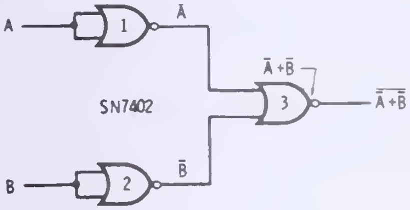
   ____

   ____

7. Test the circuit to verify your theory. Did it work as you predicted?

   ____

8. Connect the combinational logic circuit of Figure 46-4 using the SN7402.



INPUTS		EXPRESSION			OUTPUT
A	B	A	B	$\bar{A}+\bar{B}$	$\overline{\bar{A}+\bar{B}}$
0	0				
0	1				
1	0				
1	1				

Figure 46-4 Combination NOR gate circuit and table.

9. Complete the truth table in Figure 4604 for outputs at the designated points. Then test the combinational logic circuit. Does it do what you predicted by truth table?

   ____

10. Open the circuit power switch and connect NOR gate 4 as a NOT gate. Attach the output in Figure 46-4 to the input of NOR 4. Connect the LED to the output of NOR 4. Invert the last stage of the truth table of Figure 46-4 and predict the type of gate achieved by your modified circuit.
11. Close the circuit switch and test your prediction. Was it correct?

    ____

12. Open the circuit switch and disconnect the circuit.

Part C: NOT Logic

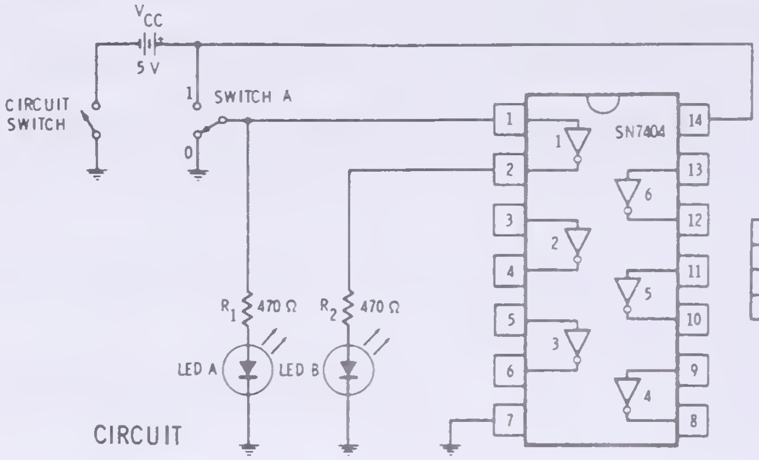
1. Using the SN7404 hex-inverter IC of Figure 46-5 build the IC test circuit and check gate 1.
2. Turn on the circuit switch and record the 1s and 0s of the output in the truth table of Figure 46-5 for the input alternatives.
3. With a multimeter, measure the voltage values of a representative 1 and 0 of this gate.

   A 1 = __________v, while a 0 = __________v.

4. Test the other five gates to verify that they are operating properly.
5. Open the circuit switch and combine gates 1 and 2 as indicated in Figure 46-6.
6. Close the circuit switch and test the combination gate. Record the 1 and 0 outputs for each of the input alternatives of the truth table in Figure 46-6. What logic function does this achieve?

   ____

   ____

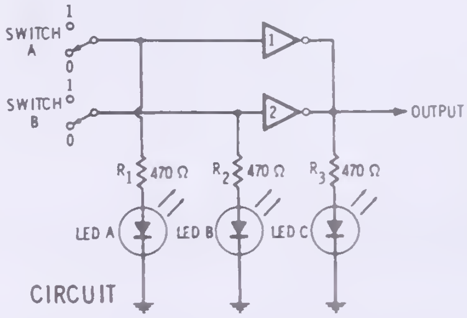


TRUTH TABLE

INPUT	OUTPUT
A	B
0	
1	

Figure 46-5 SN7404 IC test circuit and truth table.

7. Open the circuit switch and connect the output of the circuit in Figure 46-6 to the input of gate 3. Connect the LED-resistor to pin 6 and test the circuit. What logic function does it achieve?

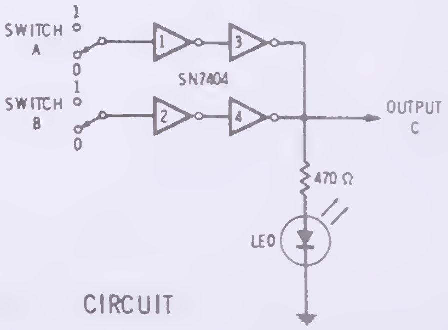


TRUTH TABLE

INPUTS		OUTPUT
A	B	C
0	0	
0	1	
1	0	
1	1	

Figure 46-6 Combination NOT gate circuit and table.

8. Open the circuit switch and combine gates of the inverter to form the circuit of Figure 46-7.
9. Close the circuit switch and test the circuit. Record the 1 and 0 outputs of C in the truth table of Figure 46-7 for the given input alternatives. What gate function does this achieve?



TRUTH TABLE

INPUTS		OUTPUTS	
A	B	C	0
0	0		
0	1		
1	0		
1	1		

Figure 46-7 Cascaded double-inverter circuit.

Name ______________________________

10. Open the circuit switch and add the output of Figure 46-7 to the input of gate 5. Move the LED to the output of gate 5. What gate function do you predict the output will demonstrate?

____

____

11. Close the circuit switch and test the circuit. Record your findings at the D output of the truth table in Figure 46-7. Was your prediction correct?

____

12 Open the circuit switch and disconnect the components. Return all parts to the storage area.

Analysis:

1. In Part A, complete Figure 46-8 showing the outputs for each logic gate listed.

INPUTS		OUTPUTS			
A	B	NAND	AND	OR	NOR
0	0				
0	1				
1	0				
1	1				

Figure 46-8 General truth table.

2. Make a sketch of the five logic circuit combinations accomplished with the SN7402. Show the actual logic gate combinations used.

3. In any of the combined inverter gate combinations, why is the 0 considered a predominate factor?

____

____

4. Make a sketch of the five logic functions achieved by the SN7404.

Activity 47—Motor-Driven Timers

Name ________________________________ Date ______________ Score __________

Objectives:

The motor-driven timer provides a wide variety of timing actions for industrial circuit applications. In its simplest form this timer has an electric drive motor, ratchet release coil, and a ratchet dial that is held stationary until released. When the timing cycle reaches its set-time, the ratchet is released and the dial resets itself by spring action. Both on delay and off delay reset timers are available. More sophisticated reset timers permit a wide range of timing operations in a single unit.

In this activity a simple reset timer will be used to build a load control circuit that produces either interval or delay timing operations. Initially, when the timer is energized by the control switch, load A is turned on and load B is turned off. After the expired time setting or the "time out" condition has been reached, load A is turned off and load B is turned on.

Equipment and Materials:

- Reset timer (Eagle Signal HD-50 Series).
- 7.5 W incandescent lamps with sockets (2).
- SPST toggle switch.

Procedure:

1. Refer to the timer manufacturer's product manual before attempting to complete this activity.
2. Wire the reset timer for the "on delay" operation of Figure 47-1.

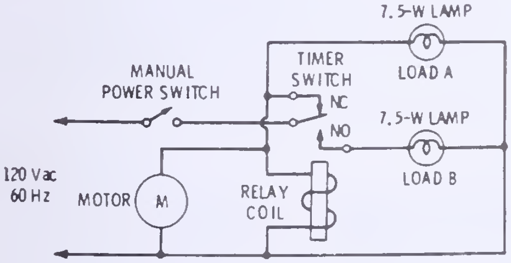


Figure 47-1 Reset timer with on delay operation.

3. Adjust the time setting dial by pulling it out and turning it to a desired setting. Releasing the dial automatically locks it in the new setting.
4. Turn on the manual power switch and describe the operating condition of loads A and B.

   ____

   ____

5. When the dial setting trips, describe the operating condition of the load and the motor.

   ____

   ____

6. Start a new operation cycle by opening the control switch momentarily, then turning it on again. After the cycle has been in operation for a few seconds, momentarily open the control switch, then close it. What action does this initiate?

Analysis:

1. What are some industrial applications of a reset timer?
2. Could this timer be modified to achieve a different function of some type? Explain.
3. Explain the difference between *interval* and *delay* timers.

Activity 48—Digital Timers

Name ______________________ Date ______________ Score __________

Objectives:

Digital timers are a rather recent addition to the timer field. This type of timer employs a time base generator or oscillator, a counter, and a load driver. The counter part of the system frequently has several output terminals that permit some selection of time ranges. Control ranges of 1T, 2T, 4T, 8T, 16T, and 32T are typical. Each output is rated in terms of the time base (T) of the generator.

In this activity you will employ the SE/NE555 timer IC as the time base generator of a simple digital timing system. The output of the generator will be counted and divided to some extent by the range of the system. Through this circuit investigation you will see and actually work with the basic parts of a simple digital timing system. Commercially designed timers of this type are usually housed in an enclosure that does not permit access to component parts. These timers generally do not employ moving parts and are all solid state. The timing period is very accurate and usually ranges from microseconds to hours.

Equipment and Materials:

- SE/NE555 IC.
- 200 kΩ, 1/8 W resistors (2).
- 390 Ω, 1/8 W resistor.
- Light-emitting diode.
- 4 µF, 25v dc capacitor.
- 0.01 µF, 100v capacitor.
- 50 µF, 25v dc capacitor.
- SPST toggle switches or push buttons.
- SN7490 IC.
- Circuit mounting board.

Procedure:

1. Construct the experimental digital timer circuit of Figure 48-1 by first connecting the time base generator. Do not energize the SN7490 at this time.
2. Determine the charging time of the circuit by the $t_c = 0.693\,(R_A + R_B)\,C_1$ formula. Test the accuracy of the circuit. Record your findings.
3. Determine the discharge time of the circuit by the $t_d = 0.693R_B\,C_1$ formula. Test the accuracy of the circuit. Record your findings.

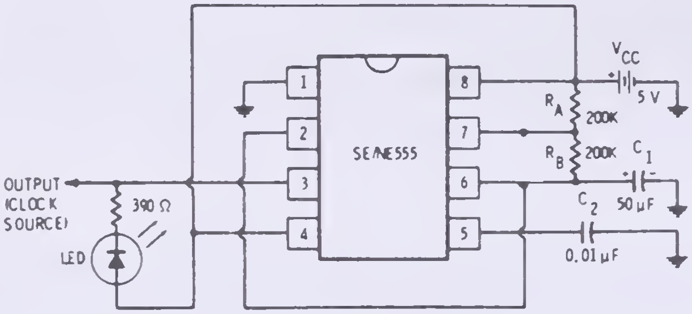
   ____

4. Turn off the power supply and complete the SN7490 counter IC. Connect it to the same power source used by the 555. Connect the second LED indicator to the D output of the 7490 IC. Connect the IC clock source to the output (pin 3) of the 555.
5. Turn on the power source and count the number of timing cycles needed to energize the 7490 LED readout.

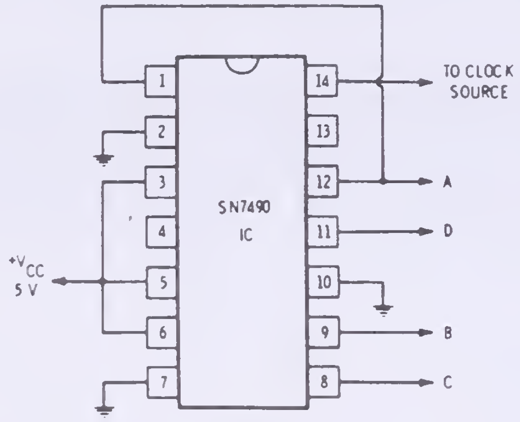
   What mathematical function does this represent?

   ____

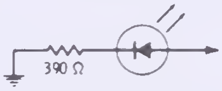
   ____



TIME BASE GENERATOR



COUNTER



LED TESTER CIRCUIT

Figure 48-1 Digital timer circuit.

6. Turn off the power source and move the LED readout of the 7490 to output A. Turn on the power again and determine the counting cycles needed to energize the LED.

__________ timing cycles.

What mathematical function does this represent?

____

____

7. Turn off the power supply and alter the SN7490 circuitry as indicated in Figure 48-2. Change C_1 of the time base generator to 4 µF.

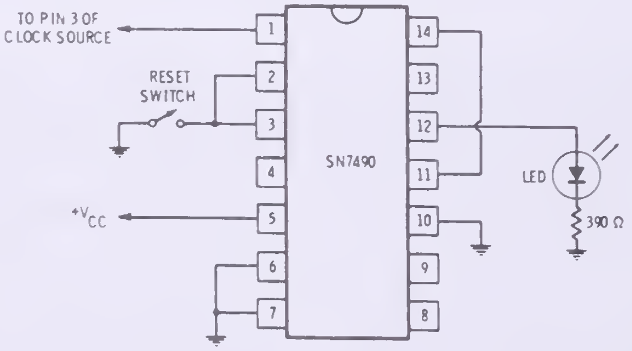


Figure 48-2 Modified counter circuit.

Name ______________________________

8. Turn on the power supply and open the reset switch. Close the switch during a time when the time base generator LED is off. Then count the number of timing cycles needed to energize the SN7490 LED.

   __________ timing cycles.

   Then count the number of timing cycles needed to turn off the LED. What does this represent as an output of the IC?

   ____

   ____

Analysis:

1. How could the digital timer of this experiment be extended? Name two ways.

   ____

   ____

2. How can the digital timer of this experiment be made variable?

   ____

   ____

3. Would it be advantageous to have a reset switch an actual digital timer? Why?

   ____

   ____

Activity 49—Control With Dc Stepping Motors

Name ____Date ____________________Score ____________

Objectives:

The dc stepping motor represents a type of rotary actuator designed to achieve automatic position control of industrial processing equipment. The motor shaft will move a specific number of degrees with each pulse of electrical energy. The amount of angular displacement produced by each pulse can then be repeated precisely with each succeeding pulse. The resulting output of this motor is used to accurately locate or position a work surface automatically for some manufacturing operation.

In this activity, you will construct a manual switching circuit for a dc stepping motor. This particular motor is capable of moving in 1.8° steps in either direction. The direction of rotation is determined by the switching sequence of the motor coils. Only four coils are utilized in the construction of this motor. As the motor is stepped through a switching sequence, different coil combinations cause the rotor to move to a new location for each step. Only two of the four coils are energized during an operational step.

In Part A of this activity, you will become familiar with the manual switching logic needed to actuate a dc stepping motor to a specific position. You will also reverse the direction of rotation by changing the logic sequence order of the switch combinations. Through this experience you will be able to observe how switching logic is transformed into rotary motion.

In Part B of this activity, driver transistors are employed as control elements. Toggle switches are used in this case to achieve manual control of the logic sequence through transistor conduction. In an actual stepping motor control circuit, driver transistors are switched by pulses from a logic control center. The next activity is devoted to logic circuitry needed to achieve automatic control of a stepping motor.

Equipment and Materials:

- Dc stepping motor (Superior Electric Co. M-111-FD 310 or equivalent).
- 0-15v dc, 1 A Power supply.
- 50 Ω, 20 W resistor.
- 470 Ω, 1/8 W resistors (4).
- 1 kΩ, 1/4 W resistor.
- SPST toggle switches (4).
- IN4004 diodes (4).
- 2N3053 transistors (4).
- SPDT toggle switches (2).
- IC circuit construction board.

Procedure:

1. Construct the manual switching control circuit for a dc stepping motor in Figure 49-1.
2. Turn on the dc power supply and adjust it to 15v dc before closing any of the logic switches. Then turn off the power supply.
3. Set the logic switches to correspond to step 1A of Figure 49-2. Apply power to the motor by turning on the dc power supply.
4. Note the direction that the rotor moves and its initial location.

   Rotational direction __________

   You may want to place a strip of masking tape near the rotor shaft and mark its initial location. You may need to make a position locating pointer of tape and attach it to the shaft as an indicator of its position change.

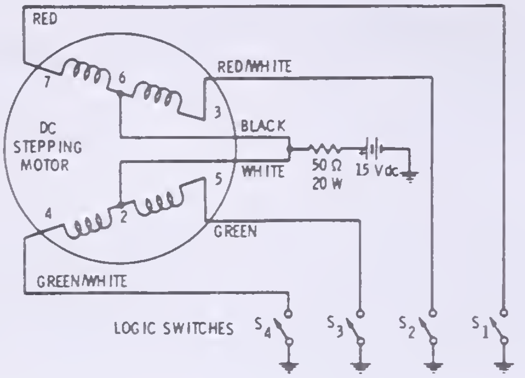


Figure 49-1 Manual switching control circuit.

Step	S_1	S_2	S_3	S_4
1A	on	off	on	off
2	on	off	off	on
3	off	on	off	on
4	off	on	on	off
1B	on	off	on	off

Figure 49-2 Logic switch settings.

5. Set the switches to steps 2, 3, 4, and finally to step 1B. Note that steps 1A and 1B are identical.
6. Starting at step 1B, set the switches for steps 4, 3, 2, and 1A in this order.
7. Note the direction of rotation and position of the rotor with reference to its starting location.

   Rotational direction __________.
8. Steps 1A and 1B in practice are referenced as the same step. They were used in this activity as a basis for establishing the rotational direction control logic sequence. Henceforth they will be referred to as step 1.
9. Starting with the switches at step 1, sequence the steps 1, 2, 3, 4; 1, 2, 3, 4; 1, 2, 3, 4; and 1, 2, 3, 4.
10. If each step achieves 1.8° of rotation, what is the total rotational movement?

    ____
11. If a protractor is available, you may want to mark the starting position and sequence the switching action and check the final location.
12. The rotational sequence is cyclic, and may be started at any position as long as it is maintained in the same logical order.
13. Turn off the power supply. If you have time to do Part B, remove only the switches of the circuit. Otherwise disconnect the entire circuit and return all parts to the storage area.

Part B: Manually Controlled Drivers

1. Connect the manually controlled dc stepping motor with transistor drivers in Figure 49-3.
2. The switching action of this motor can be sequenced to turn in either direction as in Part A of the activity. Repeat the stepping sequence of Figure 49-2 from 1A to 1B. Note the direction of rotation.
3. Reverse the stepping sequence from steps 1B to 1A and note the direction change.
4. An important aspect of the switching sequence can be seen by carefully studying Figure 49-2. Switches 1 and 2, you should note, are always in opposite switching states for each step. The same occurs with switches 3 and 4; when one is "on," the other is in the "off" state. These switches could be easily combined by two SPDT switches for control of all four transistors.

Name ____

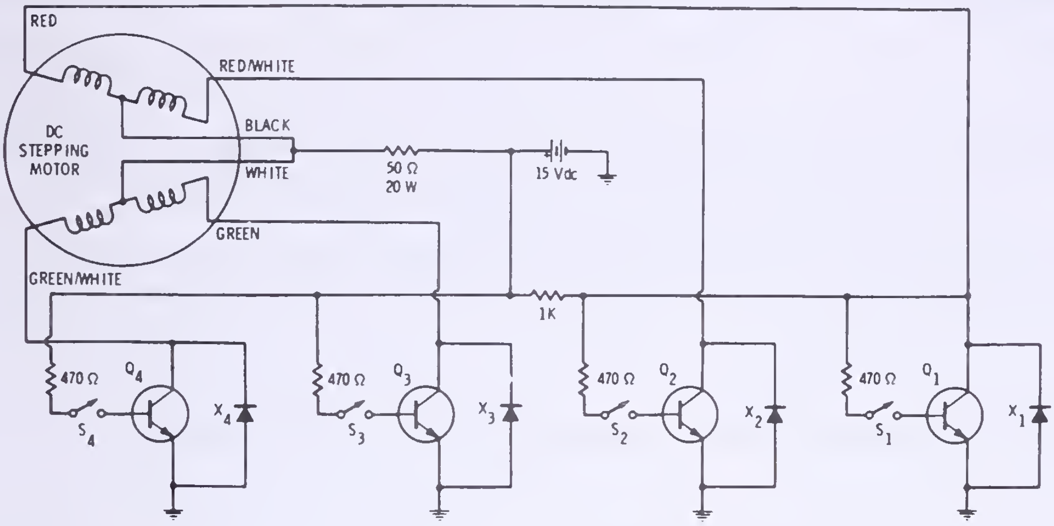


Figure 49-3 Dc stepping motor with transistor drivers.

5. Refer to Figure 49-4 and modify the switches so that two SPDT switches achieve control of the four transistors.

6. When a particular switch setting applies positive voltage to the base of a transistor it causes conduction. This in turn causes the respective motor coil to be energized. The alternate switch position has no bias voltage, hence reverse bias occurs and the respective coil is off.

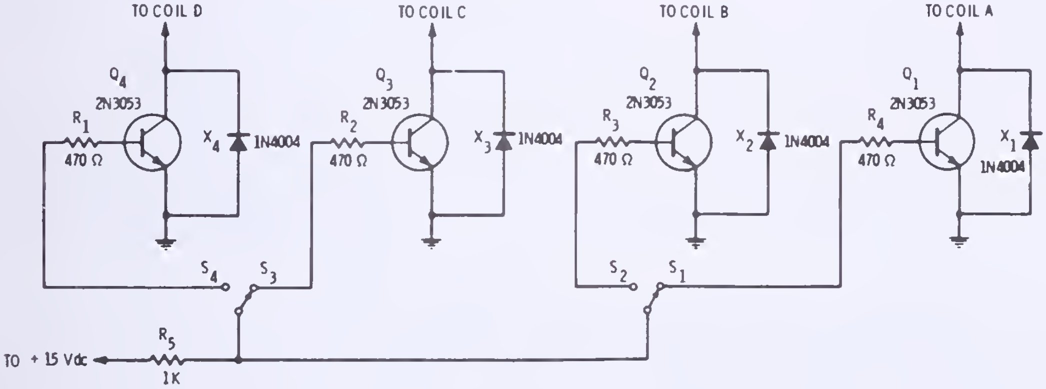


Figure 49-4 Transistor circuit controlled by two switches.

7. Cycle the motor through steps 1A to 1B with the two SPDT switches of Figure 49-4.

8. Alter the direction of rotation by reversing the switching sequence.

9. It is important to note here, that SPDT switches S_1 and S_2 could be achieved by opposite state outputs of a common flip-flop. This would, of course, permit the switching action of the motor to be achieved automatically.

10. If at all possible, leave the circuit of this activity constructed and move on to the next activity. A logic direction sequencing circuit with automatic binary control will be built for the stepping motor.

Analysis:

1. What determines the direction of rotation of a dc stepping motor?

____

____

2. If a dc stepping motor in Part A were to form a zero resting position 7.2° cw and 14.4° ccw, what would be the logic switching sequence?

3. How many sequential steps are needed to produce one complete revolution of the stepping motor used in Part A?

4. Why does forward biasing a transistor cause current to the respective coils of a stepping motor?

5. Explain how the four SPST switches of Figure 49-3 can be replaced with two SPDT switches.

6. How is it possible to control the four transistors with flip-flops?

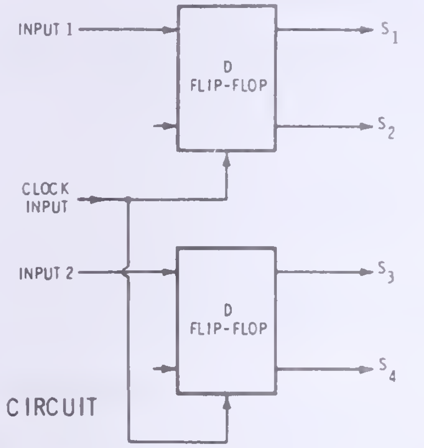
Activity 50—Automatic Stepping Motor Control

Name ______________________ Date ______________ Score __________

Objectives:

Most applications of a dc stepping motor employ some type of control circuit to energize the motor automatically. Manual sequence switching as a general rule is far too slow for typical applications.

Automatic switching circuits are used to control the rotation of a stepping motor. This can be achieved by a common "D" flip-flop. This type of flip-flop has only one input and two opposite state outputs. See Figure 50-1 for the D flip-flop circuit.



TRUTH TABLE

STEP NUMBER	INPUT 1	INPUT 2	OUTPUTS			
			S_1	S_2	S_3	S_4
3	0	0	0	1	0	1
4	0	1	0	1	1	0
2	1	0	1	0	0	1
1	1	1	1	0	1	0

Figure 50-1 D flip-flop control circuit and truth table.

Notice that the outputs of switches 1 and 3 follow the inputs of 1 and 2 respectively. You should also note that output switches 1-2 and 3-4 assume opposite states with respect to their corresponding inputs 1 and 2. This means that four valid switch settings are obtained by using only two inputs to the D flip-flops. Column 1 of the truth table refers to the corresponding step sequence number of Figure 50-2 of the manual switching circuit.

The combined inputs 1 and 2 form binary numbers ranging from zero to binary three (00-11). If these numbers are used as the inputs for the flip-flops in proper sequence, the motor will rotate by 1.8° steps. Figure 50-2 shows a summary of step numbers, binary numbers, and the corresponding decimal equivalents for the stepping sequence.

Step Number	Binary Number of Switches 1 and 3	Decimal Equivalent
1	11	3
2	10	2
3	00	0
4	01	1
1	11	3

Figure 50-2 Stepping sequence.

The next function of automatic control is to devise a method by which a proper sequence of binary numbers is developed and applied to the inputs of the two flip-flops. The method employed here is one of a decoding process using NAND gates. See Figure 50-3.

When power is applied to an automatic control circuit, the flip-flops will assume some valid state and apply their output to the driver transistors. This state is sensed by the four NAND gates of IC_1 and the next correct step for either direction is set up by the gates of IC_2. IC_3 then operates in conjunction with the forward/reverse enable switch to determine which of the two possible direction sequences will be applied to the flip-flops. The forward/reverse switch is used to enable or disable each half of IC_3, which influences the direction of rotation.

With power applied to the motor, driver transistors, decoding network, and the direction control switch in either position, stepping does not occur until the flip-flops receive a clock pulse. This means that rotation of the stepping motor is directly dependent upon the rate by which clock pulses arrive at the flip-flops. Precision control of the motor is based upon the availability of a finite number of clock pulses applied to the flip-flop inputs.

In this activity you will build an automatic directional sequence controller for a dc stepping motor. Through this activity, you will see how a number of ICs are connected together to achieve a specific operational sequence.

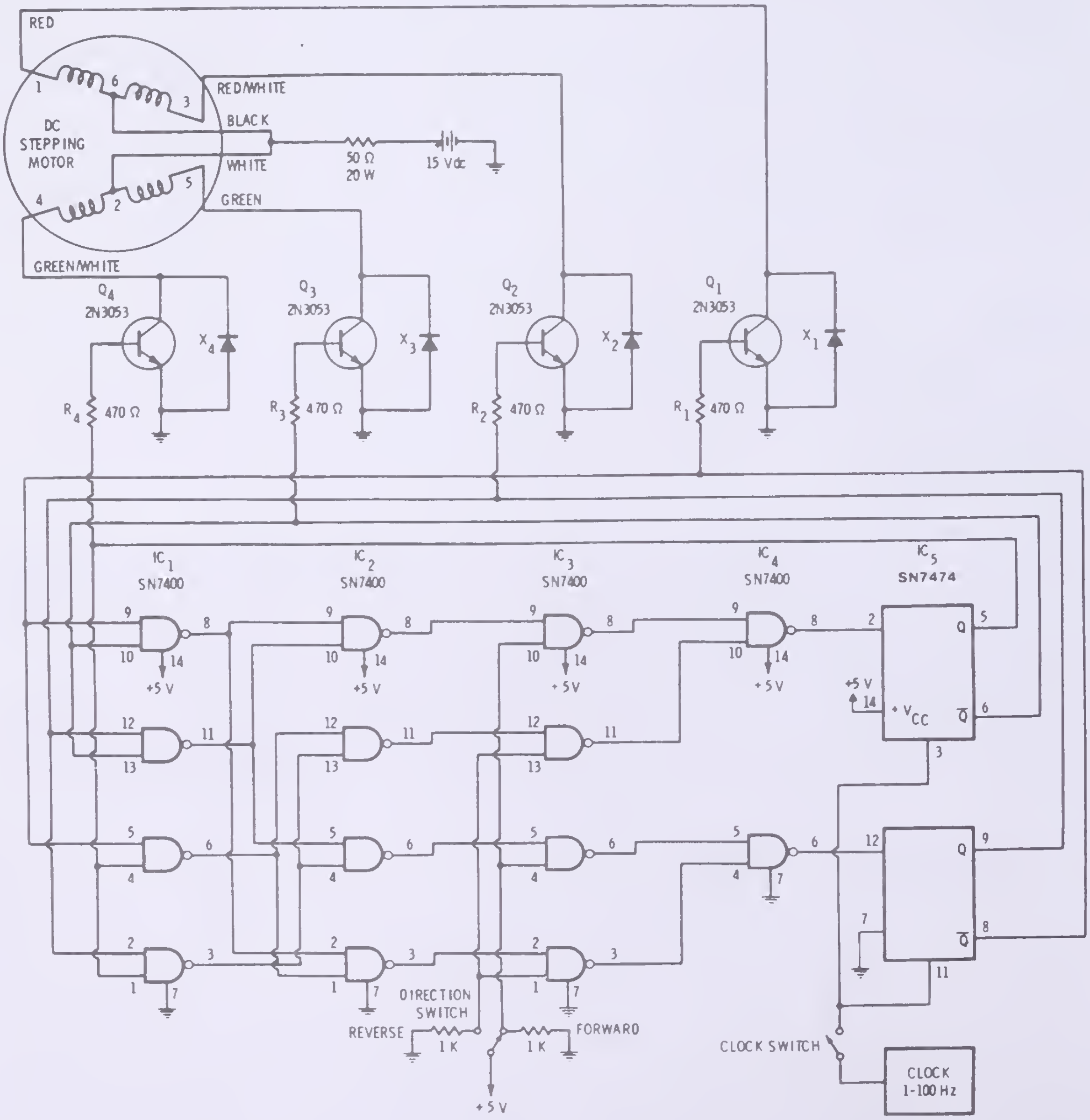


Figure 50-3 Circuit for applying binary sequence to flip-flops.

Name ____

You will also be able to test and observe the functional steps of a composite circuit in operation. Stepping motor applications of this type are commonly used to control the work surface of industrial robots.

Equipment and Materials:

- Dc stepping motor (Superior Electric Co. M-111-FD3/0 or equivalent).
- 0-15v, 1 A power supply.
- 0-5v, 1 A power supply.
- 50 Ω, 20 W resistor.
- 470 Ω, 1/8 W resistors (4).
- 1 kΩ, 1/4 W resistors (2).
- Dc voltmeter or multimeter.
- 2N3053 transistors (4).
- SPDT toggle switch.
- SPST toggle switch.
- SN7400 dual-in-line ICs (4).
- SN7474 IC.
- IC circuit construction board.
- Clock circuit or generator.
- Oscilloscope.
- Electronic multifunction meter.

Procedure:

1. Construct the dc stepping motor automatic directional control circuit of Figure 50-3.
2. Turn on the 5v and 15v power supplies initially with the clock switch off.
3. With a dc voltmeter, measure the driver output signals at the collector of each transistor. When a transistor is conducting, the collector voltage will be low, and when it is nonconducting, it will be approximately 5v. What is the state of the transistor?

   Q_4 __________, Q_3 __________, Q_2 __________, and Q_1 __________.

   This represents the initial step of the motor.
4. Which step of the truth table of Figure 50-1 is represented by the transistors?

   Step __________.
5. Set the clock to produce one pulse per second (1 pps) and momentarily turn on the clock switch for one pulse. Repeating step 3, what is the state of the transistors?

   Q_4 __________, Q_3 __________, Q_2 __________, and Q_1 __________.

   Which step does this represent?

   Step __________.
6. Repeat Step 5 for two or three steps to determine the sequential pattern of steps. Note that a step change cannot be produced until the clock pulse is applied.
7. Place the direction switch in the reverse enable position. Repeat Steps 5 and 6 to determine the operational sequence. How does it compare with the first readings?

   ____

   ____

Name ______________________________

8. Turn on the clock switch and adjust the clock to produce 1 pulse per second. How does the motor respond?

____

____

9. Increase the clock pulse frequency to 10 pps and observe the change. To stop the motor at a specific position, simply turn off the clock switch.
10. Sequence the stepping operation so that the motor moves one half of a revolution and then returns to its original position.
11. Do not disconnect the circuit at this time if you plan to do the next activity.

Analysis:

1. How would the motor respond to 100 or 1000 pulses per second from the clock?

____

____

2. What is the function of the decoder?

____

____

3. Describe the operation of a D flip-flop.

____

____

4. What is the function of IC_3?

____

____

Activity 51—Electromagnetic Relays

Name ____ Date __________________ Score __________

Objectives:

Relays are electromagnetic switches and are excellent examples of how a magnetic field attracts a magnetic material. These devices contain a coil which creates an electromagnetic field, an armature which is constructed of a magnetic material attracted by the coil, and a number of contacts or switches which open or close when the magnetic field attracts the armature.

In this activity, you will study the electromagnetic characteristics of a relay.

Equipment and Materials:

- Multicontact relay.
- 6v lamp with socket.
- Variable dc power supply.
- Resistor: 1 kΩ.
- 6v battery.
- Connecting wires.
- Multimeter.

Procedure:

1. Prepare the multimeter to measure resistance. Measure and record the resistance of the relay coil:

   __________ Ω

2. Using the multimeter, determine how many normally open and normally closed contacts are used with your relay.

   Number of normally open contacts = __________

   Number of normally closed contacts = __________

3. Construct the circuit illustrated in Figure 51-1. Be sure that the variable dc power supply is adjusted to zero. The multimeter should be adjusted to measure dc current on the highest range.
4. Slowly adjust the variable dc power supply from zero until the 6v lamp is turned on. Record the current measured by the multimeter when the relay is energized. This is the pickup current:

   Pickup current = __________ mA.

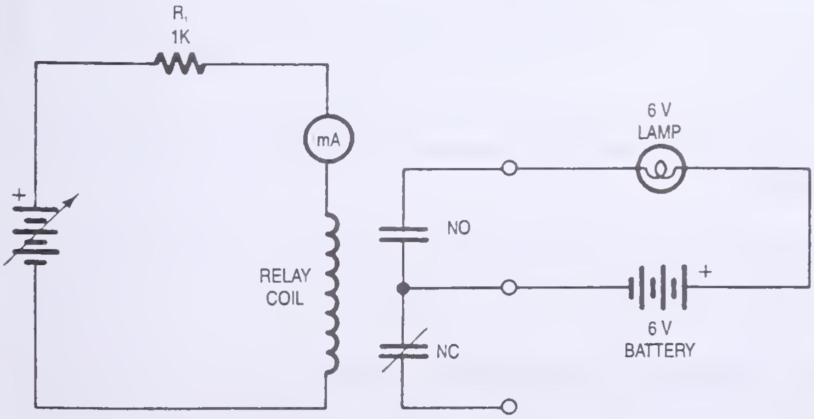


Figure 51-1 Circuit using electromagnetic relay.

5. Slowly adjust the variable dc power supply toward zero until the 6v lamp is turned off. Record the current measured by the multimeter when the relay deenergized. This is the dropout current:

   Dropout current = mA

6. Turn the variable power supply off.
7. Alter the circuit to cause it to be like that in Figure 51-2.

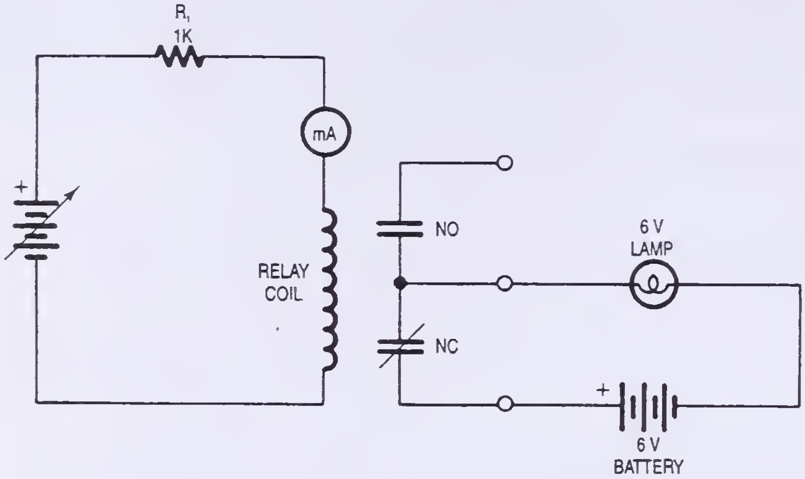


Figure 51-2 Circuit from Figure 51-1 with relay contacts reversed.

8. You will notice that the only difference in the two circuits is the type of contacts used. In Step 3, the normally open contacts were used. In this procedure the normally closed contacts are used, causing the lamp to remain on until the relay is energized.
9. Adjust the variable dc power supply and record the pickup and dropout currents as you did in Steps 4 and 5.

   Pickup I = __________ mA

   Dropout I = __________ mA

10. How do the currents recorded in step 9 compare with the current recorded inSteps 4 and 5?

    ____

11. How did the action of the 6v lamp in Steps 4 and 5 compare with the action of the lamp in Step 9?

    ____

Analysis:

1. What are normally open contacts?

   ____

2. What are normally closed contacts?

   ____

3. What is meant by the term pickup current?

   ____

4. What is meant by the term dropout current?

   ____

5. Using Ohm's law, compute the voltage across the relay coil when the relay is energized (see steps 1 and 4):

   $V = I \times R =$ __________v

Activity 52—Programmable Logic Controllers (PLC's)

Name ______________________ Date ______________ Score __________

Objectives:

This activity requires an operational programmable logic controller in order to be performed. A variety of PLC's are commercially available through different manufacturers. The specific PLC being used will obviously have unique hardware and software operational procedures. It is recommended that the manufacturer's training manuals and programming material be reviewed before using the unit. The activities presented here are in general terms and can be adapted to conform to any available PLC. The output of the PLC can be connected to lamps, motors, solenoid valves, and a variety of devices to simulate the function of an industrial system.

In this activity, you will become familiar with the front or programming panel of a PLC, the location and identification of specific PLC components, and investigate the general programming procedure of a PLC. You will also program a relay network for the operation of a programmable logic controller and program a variety of register devices into a PLC and test the operation of the system.

Procedure:

Part A: PLC Programming Panel Familiarization

1. Attach the programming panel to the PLC and connect a variety of load devices to several selected outputs.
2. Energize the system.
3. There should be features described as network control, relay control, and numerical entry on the panel. If a CRT or liquid-crystal display is included with the unit, the program panel will have some type of cursor control section.
4. Describe the layout of the control panel of your PLC.

Part B: Identification of PLC Components

1. This activity is primarily directed toward physical component location in a functioning programmable logic controller.
2. With the aid of the manufacturer's operational manual, locate the position of each of the following hardware components:
   - A. Controller or microprocessor unit.
   - B. Input devices and the number included in the system.
   - C. Output devices and the number included in the system.
   - D. Input/output registers and the type available in the unit.
   - E. Any peripheral equipment included with the unit.
   - F. Memory unit and its capacity.
3. With the aid of the manufacturer's operational manual. Explain the component addressing procedure. Generally, a number or letter sequence is assigned to each series of components. Outline the address assignments of the PLC being used.

Part C: Programming the PLC

1. It is assumed that the PLC is properly connected to an energy source and the components are attached to the appropriate distribution rails. A variety of electrical devices should be connected to the system to simulate the response of the loads.
2. The operating procedure of each PLC will obviously vary a great deal between different systems. Review the manufacturer's programming manual and briefly summarize the procedure for starting a relay network. A network is the equivalent of a rung in the ladder diagram. This should include such things as the starting procedure, display response, address assignments, and entering data into the network

3. Develop a programming procedure that will implement a simple relay network that has one contact, one output coil, and a two state condition of operation.

Part D: Relay Network Programming

1. Using the appropriate programming procedure outlined for your system, develop a control circuit for the motor controller.
2. If the system being used has a display, make a sketch of the diagram shown on the display.
3. Test the operation of the ladder diagram to see if it achieves the desired level of control.

Part E: Component Programming

1. Using the programming procedure for your system, develop diagrams that will permit the inclusion of the following items into a functional system: (a) timer, (b) sequencer, (c) adder, (d) subtractor, (e) multiplier, (f) divider, and (g) converter.
2. Each item should be programmed into a network independently. It should have an enable contact and a method of applying data to the register and be used to actuate an output device that will drive a simulated load.
3. Make a sketch of each diagram employed and explain the general procedures for adding data to the register part of the diagram.
4. Explain how each device responds in the system when it is achieving control.

____

____

____

Name ______________________________

Analysis:

1. Assume that a programmable logic controller is used to control the operation of an ac motor. A start push button, stop push button, and an overload protection device are used in the control procedure. The start push button is latched by relay contacts when it is actuated. Draw a relay ladder diagram that would exemplify the operation of this type of circuit.

2. A sequencing operation is needed for an automatic assembly procedure. The sequence has six devices that will be placed into operation in order from 1 to 6. The sequence is then repeated in the same order. Explain how this can be achieved by the sequencer of a PLC. Draw a ladder diagram that will achieve this operation.

____

____

3. A time delay operation is needed for the control of an industrial process. This function involves a set of contacts to energize the timer, which has its output connected to a device that will be actuated 10 seconds after the contactor has been actuated. Draw a ladder diagram that will achieve this function. Explain how the circuit configuration responds.

____

____

4. An industrial control application calls for the addition of two number values of 202 and 18. The process is controlled by one enable input switch. The sum of the function appears in the output of the adder. Draw a ladder diagram that would achieve this function. Explain the operation of the circuit as if it were used in a programmable controller.

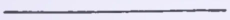
____

____

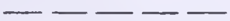
FLUID POWER SYMBOLS

FLUID CONDUCTORS:

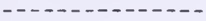
WORKING LINE (MAIN)



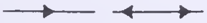
PILOT LINE (FOR CONTROL)



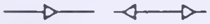
EXHAUST AND LIQUID DRAIN LINE



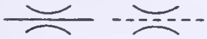
FLOW DIRECTION, HYDRAULIC



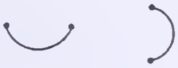
FLOW DIRECTION, PNEUMATIC



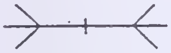
LINE WITH FIXED RESTRICTION



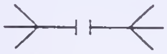
FLEXIBLE LINE



QUICK DISCONNECT WITHOUT CHECKS

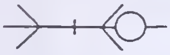


CONNECTED

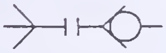


DISCONNECTED

QUICK DISCONNECT WITH ONE CHECK

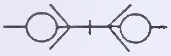


CONNECTED



DISCONNECTED

QUICK DISCONNECT WITH TWO CHECKS



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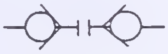
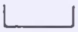


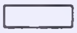
DISCONNECTED

ENERGY AND FLUID STORAGE:

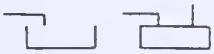
VENTED RESERVOIR



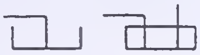
PRESSURIZED RESERVOIR



RESERVOIR WITH CONNECTING LINES

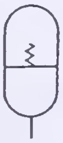


ABOVE FLUID LEVEL

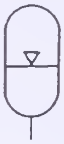


BELOW FLUID LEVEL

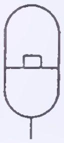
SPRING-LOADED ACCUMULATOR



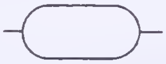
GAS-CHARGED ACCUMULATOR



WEIGHTED ACCUMULATOR

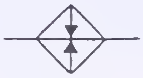


RECEIVER FOR AIR OR OTHER GASES



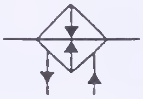
FLUID CONDITIONERS:

HEATER



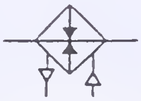
INSIDE TRIANGLES INDICATE THE INTRODUCTION OF HEAT.

HEATER



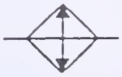
OUTSIDE TRIANGLES INDICATE A LIQUID HEATING MEDIUM.

HEATER



OUTSIDE TRIANGLES INDICATE A GASEOUS HEATING MEDIUM.

COOLER



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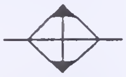
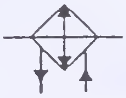
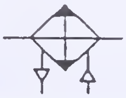


INSIDE TRIANGLES INDICATE HEAT DISSIPATION.

COOLER

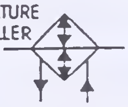


OR

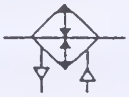


OUTSIDE TRIANGLES INDICATE A LIQUID OR GASEOUS COOLING MEDIUM.

TEMPERATURE CONTROLLER

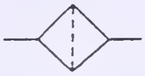


OR

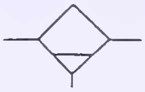


OUTSIDE TRIANGLES INDICATE A LIQUID OR GASEOUS MEDIUM.

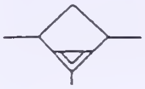
FILTER OR STRAINER



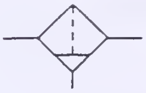
SEPARATOR WITH MANUAL DRAIN



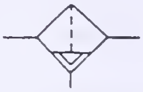
SEPARATOR WITH AUTOMATIC DRAIN



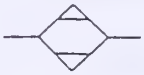
FILTER-SEPARATOR WITH MANUAL DRAIN



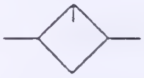
FILTER-SEPARATOR WITH AUTOMATIC DRAIN



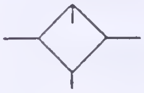
DESSICATOR (CHEMICAL DRYER)



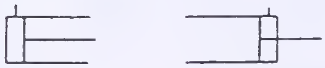
LUBRICATOR WITHOUT DRAIN



LUBRICATOR WITH MANUAL DRAIN

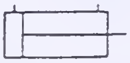


LINEAR DEVICES:

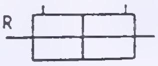


SINGLE-ACTING CYLINDERS (HYDRAULIC AND PNEUMATIC)

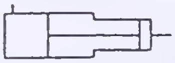
DOUBLE-ACTING CYLINDER WITH SINGLE END ROD

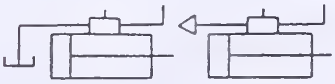


DOUBLE-ACTING CYLINDER WITH DOUBLE END ROD



PRESSURE INTENSIFIER

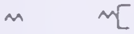


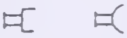


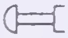
HYDRAULIC PNEUMATIC

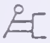
SERVO POSITIONER

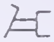
ACTUATORS AND CONTROLS:

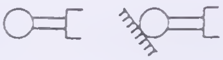
SPRING


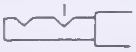
MANUAL


PUSH BUTTON


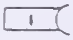
LEVER


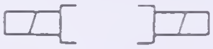
PEDAL OR TREADLE


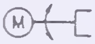
MECHANICAL


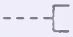
DETENT


SHORT LINE INDICATES DETENT IN USE.

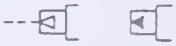
PRESSURE COMPENSATED


SOLENOID (SINGLE WINDING)


REVERSING MOTOR


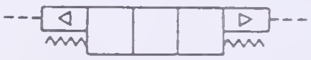
PILOT PRESSURE (REMOTE SUPPLY)


PILOT PRESSURE (INTERNAL SUPPLY)

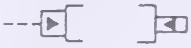
ACTUATION BY RELEASED PRESSURE


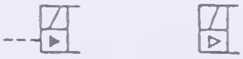
BY REMOTE EXHAUST

BY INTERNAL RETURN



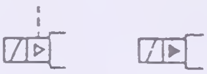
PILOT CONTROLLED, SPRING CENTERED

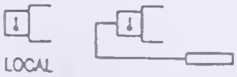
PILOT DIFFERENTIAL


SOLENOID OR PILOT


EXTERNAL PILOT SUPPLY

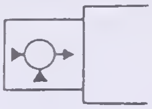
INTERNAL PILOT SUPPLY AND EXHAUST

SOLENOID AND PILOT


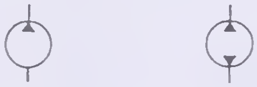
ACTUATION BY THERMAL CHANGE


LOCAL SENSING

WITH BULB FOR REMOTE SENSING

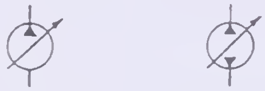
SERVO


ROTARY DEVICES:



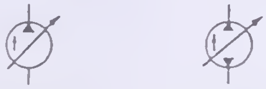
UNIDIRECTIONAL BIDIRECTIONAL

HYDRAULIC PUMP, FIXED DISPLACEMENT



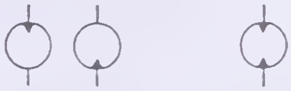
UNIDIRECTIONAL BIDIRECTIONAL

HYDRAULIC PUMP, VARIABLE DISPLACEMENT, NONCOMPENSATED



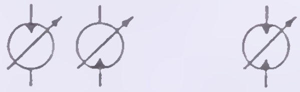
UNIDIRECTIONAL BIDIRECTIONAL

HYDRAULIC PUMP, VARIABLE DISPLACEMENT, PRESSURE COMPENSATED



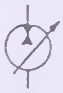
UNIDIRECTIONAL BIDIRECTIONAL

HYDRAULIC MOTOR, FIXED DISPLACEMENT



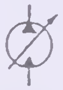
UNIDIRECTIONAL BIDIRECTIONAL

HYDRAULIC MOTOR, VARIABLE DISPLACEMENT



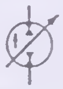
OPERATES AS PUMP IN ONE DIRECTION, AS MOTOR IN OTHER DIRECTION.

HYDRAULIC PUMP–MOTOR



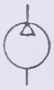
OPERATES IN ONE DIRECTION AS EITHER PUMP OR MOTOR.

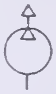
HYDRAULIC PUMP–MOTOR

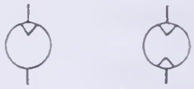


OPERATES IN BOTH DIRECTIONS AS EITHER PUMP OR MOTOR.

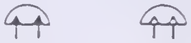
HYDRAULIC PUMP–MOTOR, VARIABLE DISPLACEMENT, PRESSURE COMPENSATED

PNEUMATIC PUMP, FIXED DISPLACEMENT

COMPRESSOR

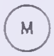
PNEUMATIC PUMP, FIXED DISPLACEMENT

VACUUM PUMP

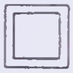
PNEUMATIC MOTOR


UNIDIRECTIONAL BIDIRECTIONAL

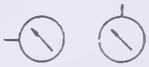
OSCILLATOR


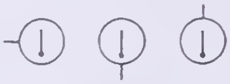
HYDRAULIC PNEUMATIC

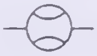
ELECTRIC MOTOR


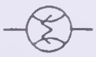
INTERNAL COMBUSTION ENGINE


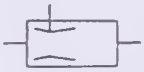
INSTRUMENTS AND ACCESSORIES:

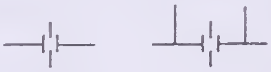
PRESSURE INDICATING AND RECORDING


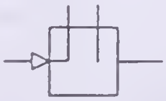
TEMPERATURE INDICATING AND RECORDING


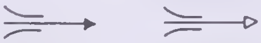
FLOW-RATE METER


TOTALIZING METER


VENTURI


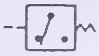
ORIFICE PLATE


PITOT TUBE


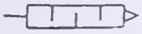
NOZZLE


HYDRAULIC PNEUMATIC

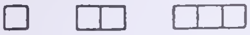
PRESSURE SWITCH



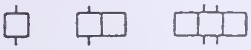
MUFFLER



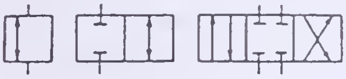
VALVES, BASIC SYMBOLS:



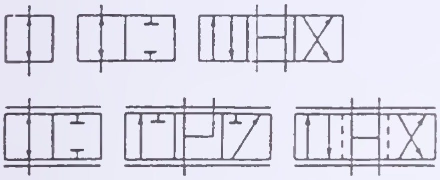
ENVELOPES



ENVELOPES WITH PORTS

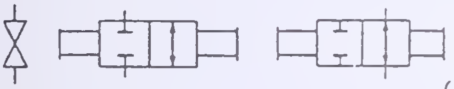


PORTS INTERNALLY BLOCKED



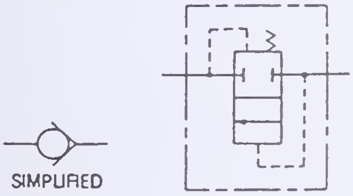
FLOW PATHS INTERNALLY OPEN

TWO-WAY VALVES (2-PORTED):



SIMPLIFIED OFF ON

MANUAL SHUTOFF ON-OFF VALVE

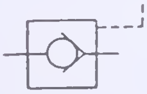


SIMPLIFIED

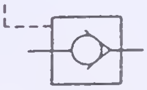
COMPOSITE
(FLOW BLOCKED TO RIGHT;
PERMITTED TO LEFT.)

CHECK VALVE

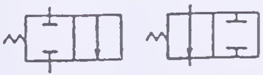
CHECK VALVE,
PILOT-OPERATED TO OPEN



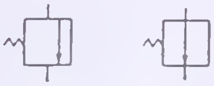
CHECK VALVE,
PILOT-OPERATED TO CLOSE



TWO-POSITION TWO-WAY VALVES



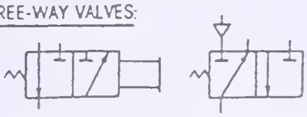
NORMALLY CLOSED NORMALLY OPEN



NORMALLY CLOSED NORMALLY OPEN

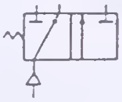
INFINITE-POSITION TWO-WAY VALVES

THREE-WAY VALVES:



NORMALLY OPEN NORMALLY CLOSED

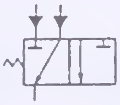
TWO-POSITION



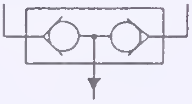
PRESSURE IS DISTRIBUTED FIRST TO ONE PORT, THEN THE OTHER.

TWO-POSITION DISTRIBUTOR

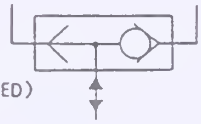
TWO-POSITION,
TWO-PRESSURE



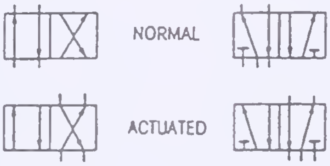
DOUBLE CHECK VALVE
WITHOUT CROSS BLEED
(ONE-WAY FLOW)



DOUBLE CHECK VALVE
WITH CROSS BLEED
(REVERSE FLOW PERMITTED)



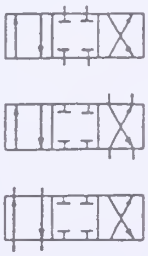
FOUR-WAY VALVES:



NORMAL

ACTUATED

TWO-POSITION

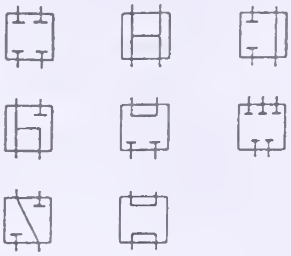


NORMAL

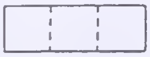
ACTUATED LEFT

ACTUATED RIGHT

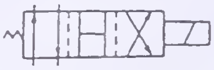
THREE-POSITION



TYPICAL FLOW PATHS FOR CENTER CONDITION OF THREE-POSITION, FOUR-WAY VALVES

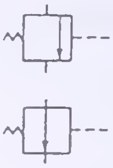


TRANSITION SYMBOL



TWO-POSITION, SNAP ACTION WITH TRANSITION

INFINITE POSITIONING
(BETWEEN OPEN AND CLOSED):

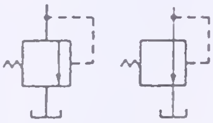


NORMALLY CLOSED

NORMALLY OPEN

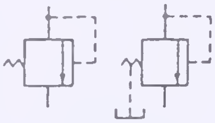
PRESSURE CONTROL VALVES:

PRESSURE RELIEF

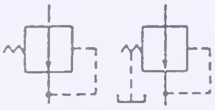


NORMAL ACTUATED (RELIEVING)

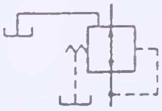
SEQUENCE

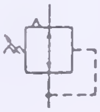


PRESSURE REDUCING



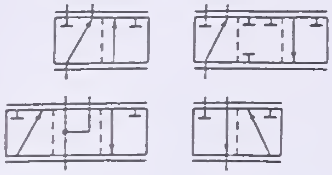
PRESSURE REDUCING AND RELIEVING



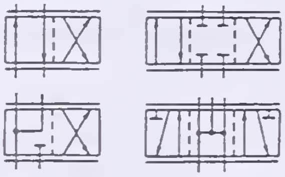


AIR LINE PRESSURE REGULATOR (ADJUSTABLE, RELIEVING)

INFINITE POSITIONING VALVES:

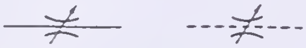


THREE-WAY VALVES



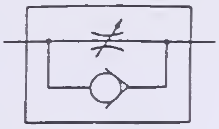
FOUR-WAY VALVES

FLOW-CONTROL VALVES:

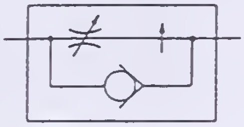


ADJUSTABLE, NONCOMPENSATED
(FLOW CONTROL IN EACH DIRECTION)

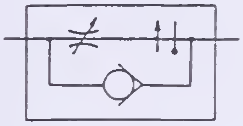
ADJUSTABLE,
WITH BYPASS



FLOW CONTROLLED TO RIGHT,
FLOW TO LEFT BYPASSES CONTROL.

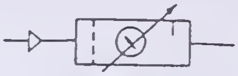


ADJUSTABLE AND PRESSURE
COMPENSATED, WITH BYPASS

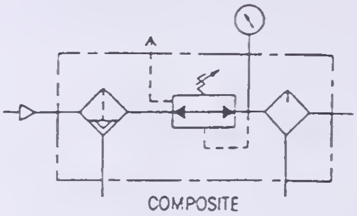


ADJUSTABLE, TEMPERATURE
AND PRESSURE COMPENSATED

AIR LINE ACCESSORIES:



SIMPLIFIED



COMPOSITE

FILTER, REGULATOR, AND LUBRICATOR

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